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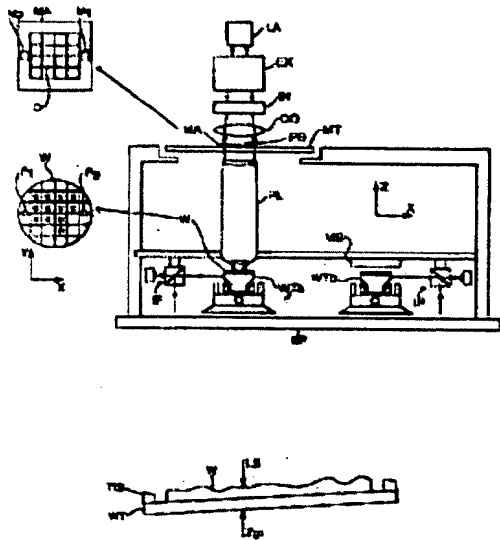
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(54) OFF-AXIS LEVELING IN LITHOGRAPHIC PROJECTION APPARATUS



(57)Abstract:

PROBLEM TO BE SOLVED: To avoid for the necessity to relate origins of two interferometer systems by controlling position of a second substrate table in a first direction in accordance with a height map and a measured position, during exposure of a target portion of a substrate.

SOLUTION: A projection beam PB of radiation is supplied from a radiation system A to a mask MA, which is held with a first substrate table MT. An irradiated portion of a mask of a second substrate table WT is imaged on a target portion C of a substrate W by using a projection system PL. Position of the second substrate table WT in a first direction is controlled in accordance with a position measured with a height map and a position measuring means IF, during exposure of the target portion C of the substrate W. As a result, necessity to relate origins of two interferometer systems can be

evaded.

* NOTICES *

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- 1.This document has been translated by computer. So the translation may not reflect the original precisely.
- 2.**** shows the word which can not be translated.
- 3.In the drawings, any words are not translated.

CLAIMS

[Claim(s)]

[Claim 1]a radiation system (LA.) for being a lithography projection apparatus and supplying a projection beam (PB) of radiation The 1st object table (MT) provided with a mask holder for holding Ex, IN, and CO; mask (MA);. Have a substrate holder for holding a substrate (W). The 2nd movable object table (WT); projection system [for carrying out image formation of the irradiated part of this mask on a target portion (C) of this substrate] (PL);, and the above-mentioned 2nd object table, In a projection device containing positioning system; for the above-mentioned projection system to move the above-mentioned mask parts on the above-mentioned substrate between an exposure station and a measuring station which are made to image formation, the 2nd object table of; above has the physical reference surface fixed to it, and further a projection device, Two or more points on the surface of a substrate (W) which was located in the above-mentioned measuring station and held on the above-mentioned substrate holder, A height map preparing means about the above-mentioned physical reference surface constituted and allocated so that height might be measured and the height map might be made; after being located in the above-mentioned

exposure station and moving the above-mentioned 2nd object table to the above-mentioned exposure station, During exposure of position measuring means [for measuring a position in the 1st vertical direction substantially to the above-mentioned substrate face of the above-mentioned physical reference surface],, and the above-mentioned target portion, Equipment having control means; constituted and allocated so that a position of the above-mentioned 2nd object table in the 1st direction of the above might be controlled at least according to the above-mentioned position measured by the above-mentioned height map and the above-mentioned position measuring means.

[Claim 2]Equipment formed in equipment by Claim 1 so that the above-mentioned control means may control inclination around one axis of the above-mentioned 2nd object table vertical to the 1st direction of the above at least further according to the above-mentioned height map.

[Claim 3]Equipment containing a level sensor constituted and allocated in equipment by Claim 1 or Claim 2 so that the above-mentioned height map preparing means might measure a position in the 1st direction of the above of a linearity array of a point.

[Claim 4]Equipment containing a level sensor (10) constituted and allocated so that the above-mentioned height map preparing means might measure a position of a measurement beam reflected by the surface which should measure a position in the 1st direction of the above in equipment by Claim 1, Claim 2, or Claim 3.

[Claim 5]The above-mentioned level sensor (10) in equipment by Claim 4 an image of the :projection lattice (113); above-mentioned projection lattice, A projection optical system (114) for projecting on the surface which should measure a position in the 1st direction of the above; A detection lattice (126), Equipment containing a detector (128) for detecting a moire figure which was able to do light reflected by the above-mentioned surface in order to make an image of the above-mentioned projection lattice on the above-mentioned detection lattice when detecting optical system [for converging] (121); and the above-mentioned image of the above-mentioned projection lattice lapped with the above-mentioned detection lattice.

[Claim 6]Equipment with which the above-mentioned projection optical system and the above-mentioned detecting optical system comprise a reflexivity optical element intrinsically including a radiation source (111) constituted and allocated in equipment by Claim 5 so that the above-mentioned level sensor might illuminate the above-mentioned projection lattice with multicolor radiation further.

[Claim 7]In Claim 1 thru/or any of Claim 6 or equipment by one, the above-mentioned height map preparing means, Equipment including a position detecting means (1F) for detecting a position in the 1st direction of the above of the above-mentioned 2nd object table simultaneously with measurement by level sensor (10) for detecting a position in the 1st direction of the above of the surface of the above-mentioned substrate in respect of [describing above] plurality, and the above-mentioned level sensor.

[Claim 8]Equipment with which the above-mentioned position detecting means contains an interferometer in equipment by Claim 7.

[Claim 9]Equipment with which the above-mentioned position measuring means contains an image sensor attached to the above-mentioned 2nd object table in Claim 1 thru/or any of Claim 8 or equipment by one, and the above-mentioned physical reference surface contains the upper surface of the above-mentioned image sensor.

[Claim 10]Equipment constituted and allocated in Claim 1 thru/or any of Claim 9 or equipment by one so that the above-mentioned position measuring means might measure a position about a focal plane of the above-mentioned projection system of the above-mentioned physical reference surface.

[Claim 11]In Claim 1 thru/or any of Claim 10 or equipment by one, the above-mentioned 2nd object table has two or more estranged physical reference surfaces, Equipment constituted and allocated so that the above-mentioned height map preparing means might measure height about a reference plane formed of two or more above-mentioned physical reference surfaces of two or more points describing above.

[Claim 12]Are Claim 1 thru/or any of Claim 11 or equipment by one, and also it is located in the :above-mentioned exposure station, . Are related with the above-mentioned physical reference surface of two or more points on the surface of a substrate held on the above-mentioned substrate holder describing above. In order to draw relative proofreading for a separate position detecting system formed in 2nd height map preparing means;, the above-mentioned measurement, and an exposure station which were constituted and allocated so that height may be measured and the height map may be made, Equipment containing calibration means; constituted and allocated so that a height map of a single board prepared by each of the above-mentioned 1st and 2nd height map preparing means might be compared.

[Claim 13]a radiation system (LA.) for being the method of manufacturing a device using a lithography projection apparatus which has the following composition, and supplying a projection beam (PB) of :radiation The 1st object table (MT) provided with a mask holder for holding Ex, IN, and CO; mask (MA);. Have a substrate holder for holding a substrate (W). A projection system (PL) for carrying out image formation of the irradiated part of 2nd movable object table (WT); and this mask on a target portion (C) of this substrate, On the above-mentioned 1st object table, a pattern. A process of providing a mask (MA) to support; in an included method, process; which carries out image formation of process; which forms a substrate (W) which has a radiation induction layer in the above-mentioned 2nd object table, and the above-mentioned irradiated part of this mask on the above-mentioned target portion of this substrate in front of the :above-mentioned image formation process, On this 2nd object table in a measuring station, two or more points on this substrate face, A process of making a height map about a physical reference surface on the above-mentioned 2nd object table in which height is shown; This 2nd object table is moved to the above-mentioned exposure station, In process; which measures a position in the 1st vertical direction substantially to the above-mentioned substrate face of the above-mentioned physical reference surface, and the above-mentioned image formation process, this 2nd object table, How having process; positioned in the 1st direction of the above at least with reference to the above-mentioned position measured in the 1st direction of the above of the above-mentioned height map and the above-mentioned physical reference surface.

[Claim 14]How to orient the above-mentioned 2nd object table with the surroundings of one axis vertical to the 1st direction of the above at least in a method by Claim 13 by referring to the above-mentioned height map in the above-mentioned image formation process.

[Claim 15]So that a square of a focal gap which covered a field of the above-mentioned target portion and integrated with the above-mentioned 2nd object table in the above-mentioned image formation process in a method by Claim 13 or Claim 14 may be made into the minimum, How to be distance [in / it arranges and / in this focal gap / the 1st direction of / between a focal plane of the above-mentioned projection lens, and

the surface of the above-mentioned substrate].

[Claim 16]In a method by Claim 13 or Claim 14, the above-mentioned image formation process includes a process of carrying out scanning image formation of the slit image on the above-mentioned substrate, And a way arrange so that a square of a focal gap which covered a field of the above-mentioned target portion and integrated with the above-mentioned 2nd object table in the above-mentioned image formation process may be made into the minimum, and this focal gap means distance in the 1st direction of the above of [between a focal plane of the above-mentioned projection lens, and the surface of the above-mentioned substrate].

[Claim 17]A process of measuring a position in each 1st direction of the above of two or more points on the method:above-mentioned substrate face where a process of making the above-mentioned height map includes the following sub processes in a method of depending either [even] Claim 13 thru/or Claim 16 describing above; simultaneously with each measurement of a position of a point on the above-mentioned substrate face. A process of lengthening each of a measuring point of process; and the above-mentioned 2nd object table which measures a position in the 1st direction of the above of the above-mentioned 2nd object table from a measuring point to which the above-mentioned substrate face for making the above-mentioned height map corresponds.

[Claim 18]A way a process of making the above-mentioned height map includes simultaneously an initial process of measuring a position in the 1st direction of the above of the above-mentioned physical reference surface, and a position in the 1st direction of the above of the above-mentioned 2nd object table, in a method by Claim 17.

[Claim 19]Are Claim 13 thru/or any of Claim 18 or a method by one, and further, Before a process of making the above-mentioned height map : A process of measuring height of two or more points on the above-mentioned wafer surface which approaches around a field on the above-mentioned substrate which should be exposed, And a method including a process of deciding local height or a tilt value of a field with the above-mentioned substrate face which should use height for [whole] the above-mentioned substrate and an inclination, and/or its height as a map from measured height.

[Claim 20]Are Claim 13 thru/or any of Claim 19 or a method by one, and further, A level sensor (10) which should be used before a process of making the above-mentioned height map when making the above-mentioned height map, A method including a process proofread by arranging this 2nd object table to a different vertical position to that from which two or more above-mentioned measurement differs, and performing measurement of plurality of a vertical position of at least one prescribed point on the above-mentioned substrate face using the above-mentioned level sensor.

[Claim 21]How to apply when making a height map of an exposed region corresponding to that to which the above-mentioned proofreading process was performed to a different exposed region of plurality on the above-mentioned substrate in a method by Claim 20, and form performed this proofreading for proofreading correction value acquired to each.

[Claim 22]A device manufactured by Claim 13 thru/or any one method of Claim 21.

[Claim 23]a radiation system (LA.) for being the method of proofreading a lithography projection apparatus which has the following composition, and supplying a projection beam (PB) of :radiation The 1st object table (MT) provided with a mask holder for holding Ex, IN, and CO; mask (MA);. Have a substrate holder for holding

a substrate (W). The 2nd, A movable object table. (WT) A projection system (PL) for carrying out image formation of the irradiated part of measuring station; which has the 1st position detecting system (20a) for measuring a position in this station of; and the above-mentioned 2nd object table, and this mask on a target portion (C) of this substrate. And an exposure station which has the 2nd position detecting system (20b) for measuring a position in this station of the above-mentioned 2nd object table; in the process; above-mentioned measuring station which forms a substrate (W) in the above-mentioned 2nd object table. A process of making the 1st height map of the above-mentioned substrate a position in the 1st vertical direction, and by measuring a position of the above-mentioned 2nd object table using the 1st position detecting system of the above simultaneously substantially [surface / of two or more points on the above-mentioned substrate face / of the above-mentioned substrate]; at the above-mentioned exposure station. A position in the 1st direction of the above of two or more points on the above-mentioned substrate face describing above, and by measuring a position of the above-mentioned 2nd object table using the 2nd position detecting system of the above simultaneously. How to contain process; [/ map / above-mentioned / 1st and 2nd height] in order to proofread process; and the 1st and 2nd position detecting systems of the above which make the 2nd height map of the above-mentioned substrate.

[Claim 24]The 1st object table (MT) which is the method of manufacturing a device using a lithography projection apparatus which has the following composition, and is provided with a mask holder for holding :mask (MA);. Have a substrate holder for holding a substrate (W). The 2nd, A movable object table (WT) an irradiated part of; and this mask. A process of providing a mask (MA) which supports a pattern in the 1st object table of the projection system (PL); above for carrying out image formation on a target portion (C) of this substrate; process; which forms a substrate (W) which has a radiation induction layer in the above-mentioned 2nd object table, and the above-mentioned irradiated part of this mask. In order to expose two or more substrates including process; which carries out image formation on the above-mentioned target portion of this substrate, in a method of repeating a process of forming the above-mentioned substrate, and a process which carries out image formation -- : -- to each substrate formed in this 2nd object table, How having process; which compares a height map of a substrate obtained one by one in order to detect correlation of a position of the degree of complaint side which may show contamination or a structural defect of process; and the above-mentioned 2nd object table which makes a height map in which height of two or more points on this substrate face is shown [Claim 25]a radiation system (LA.)-for being a lithography projection apparatus and supplying a projection beam (PB) of radiation IL'; The 1st [provided with a mask holder for holding a reflexivity mask (MA')], A movable object table (MT);. Have a substrate holder for holding a substrate (W). . Are related with a reference surface of two or more points on a flat surface of a reflexivity mask which is a projection device containing projection system (PL'); for carrying out image formation of the irradiated part of 2nd object table (WT); and this mask on a target portion (C) of this substrate, and was held on the :above-mentioned mask holder. During exposure of height map preparing means; constituted and allocated so that height might be measured and the height map might be made, and the above-mentioned target portion, Equipment having control means; constituted and allocated so that a position [in / at least / the 1st direction of the above] of the above-mentioned 1st object table might be controlled according to the above-mentioned height map.

[Claim 26]a radiation system (LA.) for being the method of manufacturing a device using a lithography

projection apparatus which has the following composition, and supplying a projection beam (PB) of radiation IL'; The 1st [provided with a mask holder for holding a reflexivity mask (MA')], A movable object table (MT); a substrate (W). A substrate holder for holding, projection system [for carrying out image formation of the irradiated part of 2nd object table (WT); which it has, and this mask on a target portion (C) of this substrate] (PL'); -- process; which provides a reflexivity mask (MA') which supports a pattern in the above-mentioned 1st object table -- a radiation induction layer on the above-mentioned 2nd object table. In an included method, a process of carrying out image formation of process; which forms a substrate (W) which it has, and the above-mentioned irradiated part of this mask on the above-mentioned target portion of this substrate The above-mentioned image formation process front, A method which has the feature in process; which positions this 1st object table in the 1st direction of the above at least with reference to the above-mentioned height map in process; which makes a height map about a reference plane on the above-mentioned 1st object table of two or more points on this mask surface in which height is shown, and the above-mentioned image formation process.

DETAILED DESCRIPTION

[Detailed Description of the Invention]

[0001]

[Field of the Invention] This invention relates to height detection and leveling of a substrate and/or a mask in a lithography device. The 1st object table which this invention is a lithography projection apparatus and is provided with the mask holder for holding the radiation system; mask for supplying the projection beam of radiation in detail; The 2nd [provided with the substrate holder for holding a substrate], Movable object table; projection system [for carrying out image formation of the irradiated part of this mask on the target portion of this substrate];, and the above-mentioned 2nd object table, It is related with the system for off-axis leveling in the projection device containing positioning system; for the above-mentioned projection system to move the above-mentioned mask parts on the above-mentioned substrate between the exposed position and measuring point which are made to image formation.

[0002]

[Description of the Prior Art] since it is easy, although this projection system may be henceforth called a "lens" --; -- it should be widely interpreted as this term including the projection system of various form containing a refractivity optical element, a reflexivity optical element, a reflective refractivity optical element, and a charged particle optical element, for example. This radiation system may also follow for any of these principles being, the element which acts in order to point to the projection beam of radiation and to fabricate or control it may also be included, and such an element may also be called a "lens" collectively or independently below. Moreover, this 1st and 2nd object table may also be called a "mask table" and a "board table", respectively. The thing of form which has two or more mask tables and/or two board tables or more may be sufficient as this lithography device. In such "multistage" equipment, an additional table may be used in parallel, or a preliminary process may be carried out on one or more tables, and, on the other hand, other one or more tables may be used for exposure.

[0003]A lithography projection apparatus is applicable to manufacture of an integrated circuit (IC), for example. In such a case, a mask (reticle) may also include the circuit pattern corresponding to each layer of this IC, and image formation can be carried out on the exposed region (die) of the substrate (silicon wafer) which applied this pattern in the layer of photosensitive materials (resist). Generally, it irradiates with every one then one by one at once through a reticle including all the networks of the die with which one wafer adjoins. irradiating with each die by exposing all the reticle patterns at once on a die in one form of a lithography projection apparatus --; -- such equipment is usually called a wafer stepper. In the alternate device usually called step and scan equipment. If it is the speed nu which this reticle pattern is sequentially scanned to the reference direction (the "scanning" direction) given by the projection beam, and this projection system generally considers it as the magnification M (generally <1) on the other hand, and scans a wafer table. It irradiates with each die by scanning a wafer table in this direction at the speed which scans the reticle table which magnification M Is the speed to apply synchronizing with parallel or reverse parallel. The further information about a lithography device which was explained here is collectable from international patent application WO97/33205, for example.

[0004]The lithography device contained the single mask table and the single board table very much till these days. However, please refer to the multistage equipment indicated to international patent application WO98; [with an available machine which now has at least two independently movable board tables], for example,/, 28665, and WO98/40791. Such a basic motion principle of multistage equipment in back, In order to expose the 1st substrate that has the 1st board table on it, while being under a projection system, The 2nd board table can move to a loading position, discharge the exposed substrate, and a new substrate is taken up, Shortly after performing some initial measurement to this new substrate and then completing exposure of the 1st substrate, it is standing by in order to transport this new substrate to the exposed position under a projection system, and repeating,, then this cycle. Thus, it is possible to improve a mechanical throughput considerably and the cost of ownership of this machine is improved as a result. He should understand that this same principle can be used only for one board table which moves between an exposed position and a measuring point.

[0005]The exposed region where the versatility on a substrate ("die") means the measurement performed to a substrate by this measuring point, for example, The determination of the spaced relationship between the reference marker on a substrate and at least one reference marker located in the outside of the substrate region on a board table (for example, standard) (X and the direction of Y) may also be included. such information can be used in an exposed position, in order for the exposed region about a projection beam to make it quick and to perform exact X and Y positioning behind --; -- the further information -- for example, WO99 / 32940 (P-0079) reference. In this Description, Z position of a substrate face in various points is related to the reference surface of a substrate holder, and preparation in the point of measurement of a height map is also indicated. However, this reference surface is defined with Z interferometer by a measuring point, and another Z interferometer is used for it in an exposed position. Therefore, it is required to get to know the exact relation between the starting points of two Z interferometers.

[0006]

[Problem to be solved by the invention]The purpose of this invention is to provide the system for carrying out off-axis leveling of a substrate which avoids the necessity of connecting the starting point of two

interferometer systems, and enables an additional improvement of positioning of an exposed region in an exposure process in a lithography projection apparatus.

[0007]

[Means for solving problem]The 1st object table which according to this invention is a lithography projection apparatus and is provided with the mask holder for holding the radiation system; mask for supplying the projection beam of radiation;. Have a substrate holder for holding a substrate. The 2nd movable object table; projection system [for carrying out image formation of the irradiated part of this mask on the target portion of this substrate];, and the above-mentioned 2nd object table, In the projection device containing positioning system; for the above-mentioned projection system to move the above-mentioned mask parts on the above-mentioned substrate between the exposure station and measuring station which are made to image formation, the 2nd object table of; above has the physical reference surface fixed to it, and it and ;projection device, Two or more points on the surface of the substrate which was located in the above-mentioned measuring station and held on the above-mentioned substrate holder, The height map preparing means about the above-mentioned physical reference surface constituted and allocated so that height might be measured and the height map might be made; It is located in the above-mentioned exposure station, After moving the above-mentioned 2nd object table to the above-mentioned exposure station, during exposure of position measuring means [for measuring the position in the 1st vertical direction substantially to the above-mentioned substrate face of the above-mentioned physical reference surface];, and the above-mentioned target portion, The equipment having the control means constituted and allocated so that the position of the above-mentioned 2nd object table in the 1st direction of the above might be controlled at least, and; according to the above-mentioned position measured by the above-mentioned height map and the above-mentioned position measuring means is provided.

[0008]The 1st object table provided with the mask holder for holding the radiation system; mask for supplying the projection beam of radiation according to the further mode of this invention;. Have a substrate holder for holding a substrate. The 2nd, The irradiated part of movable object table; and this mask. The process of being a manufacturing method of the device using the lithography projection apparatus containing the projection system for carrying out image formation on the target portion of this substrate at an exposure station, and providing the mask which supports a pattern in the 1st object table of ;above; on the above-mentioned 2nd object table, a radiation induction layer. In the included method, the process of carrying out image formation of process; which forms the substrate which it has, and the above-mentioned irradiated part of this mask on the above-mentioned target portion of this substrate The ;above-mentioned image formation process front, This 2nd object table is located in a measuring station, and Two or more points on this substrate face, The process of making the height map about the physical reference surface on the above-mentioned 2nd object table in which height is shown; This 2nd object table is moved to the above-mentioned exposure station, In process; which measures the position in the 1st vertical direction substantially to the above-mentioned substrate face of the above-mentioned physical reference surface, and the above-mentioned image formation process, this 2nd object table, With reference to the above-mentioned position measured in the 1st direction of the above of the above-mentioned height map and the above-mentioned physical reference surface, the way the process positioned in the 1st direction of the above at least has the feature is provided.

[0009]

[Mode for carrying out the invention] In the manufacturing process using the lithography projection apparatus by this invention, image formation of the pattern of a mask is carried out on the substrate selectively covered with energy sensitivity material (resist) at least. Before this image formation process, this substrate may receive various processings like an under coat, a resist application, and soft bake, for example. A substrate may receive other processings like measurement/inspection of after-exposure bake (PEB), development, postbake, and an image formation form after exposure, for example. This the processing of a series of is used as the foundation for patternizing each layer of a device, for example, IC. The layer patternized such may receive next various processings of etching, an ion implantation (doping), metalization processing, oxidation treatment, chemistry, mechanical polish, etc., etc. in which finishing of each layer was meant altogether. If some layers are necessary, new [of all the processings or the modification of those / each] will have to be carried out, and it will have to repeat to ****. After all, the array (die) of a device is made on a substrate (wafer). Next, these devices are separated from each other with dicing or a technique like sawing, each device is attached to a carrier from there, and a pin can be connected. The further information about such a process can be acquired from books, such as ISBN0-07-067250-4, in "the practical use guide of manufacture: semiconductor processing of a microchip" of Peter Van Zandt, the 3rd edition, the McGraw-Hill publishing company, and 1997, for example.

[0010] The text may explain especially in order to use the equipment by this invention for manufacture of IC, but he should understand clearly that such equipment has possibility of many of other uses. For example, it may be used for manufacture of integrated optic systems, the derivation detecting patterns for magnetic domain memories, liquid crystal display panels, thin film magnetic heads, etc. Probably, it turns out [of the term of the "reticle", the "wafer", or the "die" which a person skilled in the art uses in this text due to such an alternative use] that it should be considered for which that it is replaced by each in a respectively more general term "mask", a "substrate", and a "exposed region."

[0011] In this Description, using the term of "radiation" and a "beam", ultraviolet rays. Although (for example, a wave part (365 nm, 248 nm, 193 nm, 157 nm, or 126 nm)), extreme ultraviolet rays (EUV), X-rays, an electron, and ion are included, all kinds of the electro magnetic radiation or particle flux which is not limited to it is included. After all, this invention is explained using the reference frame of the rectangular crosses X and Y and a Z direction, and rotation of the circumference of an axis parallel to the direction of I is expressed with Ri here. furthermore -- since it requires that the context should be another -- if -- it uses here -- "vertically" -- the term (Z) points out a direction vertical to a substrate or a mask surface rather than means any of this equipment, or a specific direction.

[0012]

[Work example 1] With reference to an embodiment and an attached schematic view, this invention is explained below. Drawing 1 shows the lithography projection apparatus by this invention roughly. This equipment is :- Radiation system LA for supplying the projection beam PB of radiation (for example, UV or EUV), Ex, IN, CO;

- 1st object table (mask table) MT combined with the 1st positioning means for having a mask holder for holding mask MA (for example, reticle), and positioning this mask correctly about component PL;
- The 2nd object table (a substrate or a wafer table) WTa combined with the 2nd positioning means for

having a substrate holder for holding the substrate W (for example, silicon wafer which applied the resist), and positioning this substrate correctly about component PL;

– The 3rd object table (a substrate or a wafer table) WTb combined with the 3rd positioning means for having a substrate holder for holding the substrate W (for example, silicon wafer which applied the resist), and positioning this substrate correctly about component PL;

In a measuring station – The board table WTa. Or measurement system MS; and – for performing a measurement (characteristic display) process on the substrate held on WTb On the exposed region C of the substrate W held at the exposure station at the board table WTa or WTb (die), the irradiated part of this mask MA. Projection system (“lens”) PL(for example, system [of refraction or reflective refractivity], Mirror Group Newspapers, or field-of-view deflecting system array); for carrying out image formation is included.

[0013]This equipment is a transmission type as shown here (that is, it has a transmission type mask). However, generally a reflection type may be sufficient as it, for example.

[0014]This radiation system contains line source LA (for example, the undulator, the source of laser plasmas, electron, or ion beam source provided in the surroundings of the course of the electron beam of a mercury lamp, the Examiner laser, a storage ring, or a synchrotron) which makes the beam of radiation. It is made for the beam PB as for which this beam was let pass and made to various optics contained in this lighting system, – Ex, for example, a beam formed optical element, the integrator IN, and capacitor CO– to have desired form and the intensity distribution in that section.

[0015]This beam PB crosses mask MA currently held continuously at the mask holder on mask table MT. After passing mask MA, the beam PB passes lens PL and the lens converges the beam PB on the exposed region C of the substrate W. The exposed region C which can move the board table WTaWTb correctly by the 2nd and 3rd positioning means, for example, is different is arranged in the course of the beam PB using interferometer displacement and measuring means IF. Similarly, after taking out mask MA mechanically from a mask library, using the 1st positioning means, this mask MA can be correctly arranged about the course of the beam PB. Generally, movement of the object tables MT, WTa, and WTb is realized using a long stroke module (rough positioning) and a short stroke module (detailed positioning), although there is no ***** in drawing 1 clearly. In the case of a wafer stepper, (differing from step and scan equipment) and a reticle table may be combined only with a short stroke pointing device, and it may perform direction of a mask and detailed adjustment of a position.

[0016]These 2nd and 3rd positioning means may be constituted so that each board table WTaWTb of them can be positioned [the range including both the exposure station under projection system PL, and the measuring station under measurement system MS]. Instead, these 2nd and 3rd positioning means, It may replace by the table means of exchange for exchanging the separate exposure station, the measuring station positioning systems, and these board tables for positioning a board table to each exposure station between two positioning systems. The suitable positioning system is especially indicated to above WO98/28665, and WO98/40791. A lithography device may differ in the number of that it may have a multistage exposure station and/or a multistage measuring station and measuring stations, and the number of exposure stations mutually, and the total of the station should notice it about that it does not need to be equal to the number of board tables. The principle which makes exposure and a measuring station separate

actually holds good also in a single board table.

[0017]:1. which can use the equipment to illustrate in two different modes In step-and-repeat (step) mode, it fixes intrinsically, mask table MT is held, and all the mask images are projected at once on the exposed region C (with namely, single "flash plate"). Next, it enables it to irradiate with the exposed region C which moves board table MT in X or the direction of Y, and is different by the beam PB, and is;2. in step and scan (scan) mode. Except for not exposing the given exposed region C by single "flash plate", the same scenario is applied intrinsically. Instead, it can move in the direction (the what is called "scanning" direction of Y, for example, the direction) to which mask table MT was given at the speed v , and make the projection beam PB scan a mask image top, and; Curve, and the board table WTa or WTb is moved simultaneous [to a counter direction / at the rate of $V=Mv$] similarly. However, M is the magnification (typically $M=1/4$ or $1/5$) of lens PL. Thus, it is not necessary to compromise on resolution and the comparatively big exposed region C can be exposed.

[0018]The important factor which influences the image formation quality of a lithography device is accuracy which converges a mask image on a substrate. The range for adjusting the position of the focal plane of projection system PL is restricted actually, and since the depth of focus of the system is shallow, this means that the exposed region of a wafer (substrate) must be correctly arranged to the focal plane of projection system PL. In order to carry out this, of course, it is necessary to get to know both the position of the focal plane of projection system PL, and the position of the upper surface of a wafer. Although a wafer is ground to super-high flatness, the deviation ("the degree of complaint side" is called) from the perfect flatness of a wafer surface of sufficient size to influence for focal accuracy notably may take place. The degree of complaint side may be produced with the dirt of distortion or the wafer holder of dispersion in wafer thickness, and the shape of a wafer type, for example. Existence of the structure by previous down stream processing also influences the height (flatness) of a wafer considerably. By this invention, the cause of the degree of complaint side is mostly unrelated, and considers only the height of the upper surface of; wafer. In not mentioning specially, the "wafer surface" called below points out the upper surface of a wafer which projects a mask image on it.

[0019]According to this invention, after loading a board table with a wafer, height Z_{wafer} of a wafer surface to the physical reference surface of this board table is used as a map. The vertical (Z) position of this physical reference surface and vertical-position Z_{LS} of a wafer surface are measured in respect of plurality using the 1st sensor that this process is a measuring station and is called a level sensor, And it carries out by measuring the vertical position of this board table, and Z_{IF} simultaneously at the same point using the 2nd sensor, for example, Z interferometer. As shown in drawing 2, wafer surface height is determined as $Z_{\text{wafer}}=Z_{\text{LS}}-Z_{\text{IF}}$. Next, the board table which supports this wafer is moved to an exposure station, and the vertical position of a physical reference surface is determined again. Next, when positioning a wafer in an exposure process in a right vertical position, this height map is referred to. This procedure is explained in more detail with reference to drawing 3 thru/or drawing 6 below.

[0020]As shown in drawing 3, a board table is first moved, as the physical reference surface fixed to this board table is under level sensor LS. If this physical reference surface does not change X on a board table, Y, and Z position in the case of movement between a measuring station and an exposure station of a board table under processing of the wafer in this lithography device, and to the most important thing, a convenient

field may be sufficient as it. [some] This physical reference surface should have the character which a part of standard containing other alignment marks may be sufficient as, and makes that vertical position measure by the same sensor as measuring the vertical position of a wafer surface. In the embodiment suitable now, this physical reference surface is a reflector of the standard which inserts what is called a transmission type image sensor (TIS) in inside. Below, this TIS is explained further.

[0021]A photosensor which is indicated to US,5,191,200,B (P-0039) (a focal error detection system is called in it) may be sufficient as this level sensor, and it can consider; instead pneumatic pressure, or a capacity sensor (for example), for example. The form of the sensor using the moire figure made between the image of the projection lattice reflected according to the wafer surface and the fixed detection lattice suitable now is explained in relation to the 2nd embodiment of this invention below. This level sensor may measure the vertical position of two or more positions simultaneously, and may measure the average height of a small area to each, and may average the degree of complaint side of height spatial frequency.

[0022]Simultaneously with measurement of the vertical position of the physical reference surface by level sensor LS, the vertical position of a board table and Z_{IF} are measured using Z interferometer. Some of 3, 5, or 6 axis interferometer type instrumentation systems which are indicated to WO99/28790 (P-0077), or WOPP/32940 (P-0079) may be sufficient as this Z interferometer, for example. As for these Z interferometer systems, it is preferred to measure in that it has the same position as the measuring point in which level sensor LS proofread the vertical position of the board table in the XY plane. This may measure the vertical position by the side of [which counters] two of board table WT at the point which is in agreement with the measuring point of this level sensor, and may perform between them interpolation / by carrying out modeling. This guarantees that this Z interferometric measurement shows surely the vertical position of the board table under a level sensor, when a wafer table inclines from an XY plane.

[0023]this process -- the [this] -- it estranged in diagonal line from 1 physical reference surface, for example -- at least -- the -- repeating in 2 physical reference surface is preferred. Then, a reference surface can be defined using the height measurement from two or more positions.

[0024]The coincidence measurement of the vertical position of one or more physical reference surfaces and the vertical position of a board table establishes the point of deciding the reference plane used as the standard which should use wafer height as a map. Z interferometer of the above-mentioned kind is a displacement sensor as a matter of fact than a sensor absolutely.

Then, although zero doubling is required, it continues broadly and linear position measurement is provided highly.

on the other hand, although a suitable level sensor, for example, the above-mentioned thing, provides absolute position measurement about the reference plane (namely, nominal zero) decided outside, it comes out [the small range]. When using such a sensor, it is convenient to move a board table vertically until a physical reference surface is located in nominal zero in the middle of the time base range of a level sensor, and to read the present interferometer Z value. These one or more measurement about a physical reference surface will establish the reference plane for height map creation. Next, Z interferometer is set by zero about this reference plane. Thus, this reference plane is connected with the physical side on a board table, and a Z_{Wefer} height map is made regardless of other local factors like the degree of complaint side of the base plate to which the initial zero position and board table of Z interferometer in a measuring station are moved.

Moreover, this height map is made regardless of the drift of the zero position of a level sensor.

[0025]As shown in drawing 4, once it establishes this reference plane, in order to make a height map, a board table will be moved so that a wafer surface may be scanned under a level sensor. The vertical position of a wafer surface and the vertical position of a board table are measured in respect of the plurality of a known XY position, it lengthens from each other, and the wafer height in a known XY position is obtained. These wafer height values can form a wafer height map, and it can be recorded in a suitable form. For example, these wafer height values and XY coordinates may be memorized to the pair which does not look together to what is called an eye. Instead, by scanning a wafer at the rate of predetermined in accordance with a predetermined course, and measuring the point which takes a wafer height value at the predetermined intervals, for example, it decides beforehand and is made for the array of a simple list or a height value to come out enough for deciding this height map (parameter of a small number which determines a measured pattern and/or the starting point arbitrarily)

[0026]A great portion of movement of the board table under height map creation scan is only in an XY plane. However, if level sensor LS is form of providing only positive zero reading, in order to maintain a wafer surface at the zero position of this level sensor, also vertically, a board table is moved. Then, it derives intrinsically from Z movement of a board table which measured wafer height with Z interferometer required in order to maintain zero reading from a level sensor. However, it is preferred to use the level sensor in which the time base range which an output can linearize with regards to wafer height and linearity is quite wide. Ideally, such a time base range includes the maximum prediction of wafer height, or a permissible variation. Since according to such a sensor it is not by the capability of a short stroke board table for a scan speed to pursue the outline of a wafer by a three dimension and is restricted by the response time of a sensor, The necessity for vertical movement of the board table under this operation decreases, or is lost, and can finish a scan quickly. The large sensor of a proportional region enables it to measure height simultaneously in two or more positions (for example, array of a point).

[0027]Next, as a wafer table is moved to an exposure station and it is shown in drawing 5, this (physical) reference surface is arranged under a projection lens, and it can be made to perform measurement of that vertical position to the focal plane of this projection lens. By a preferred embodiment, this attains the detector using one or more transmission type image sensors (it explains below) physically combined with the reference surface used by pre-measurement. This transmission type image sensor can determine the vertical focusing position of the image projected from the mask under a projection lens. The course for the board table in the three dimension which can prepare this measurement, and can connect this reference plane with the focal plane of a projection lens, and maintains a wafer surface at the optimal focus can be decided. One method of performing this is calculating Z and Rx to a point, and Ry set point of a series in alignment with this scanning path. These set points decide to make the difference between wafer map data and the focal plane of an exposure slit image into the minimum using a least square method. In order to calculate easily, the relative motion of an exposure slit image and a wafer can be expressed under the condition that a slit moves to a static wafer. Then, this least square standard can be expressed as finding the value of Z (t) which gives the minimum of the following formula, Rx (t), and Ry (t) to each time t. : [0028]
[Mathematical formula 1]

$$LSQ(t) = \frac{1}{s} \cdot \frac{1}{W} \int_{-\frac{s}{2}}^{\frac{s}{2}} \int_{-\frac{W}{2}}^{\frac{W}{2}} [w(x,y) \cdot (Z(t) + x \cdot R_x(t) + y \cdot R_y(t))]^2 dx dy \quad [1]$$

However, $w(x, y)$ is a wafer height map, and exposure slits are the width s of a scanning direction, and a rectangle flat surface of length W vertical to this scanning direction.

The position is defined by $Z(t)$, $R_x(t)$, and $R_y(t)$.

Being able to express these set points and a wafer course as a function of Y (position of a scanning direction), or t (time), that is because these are connected by $Y = y_0 + vt$. However, y_0 is the starting point and v is a scan speed.

[0029] As mentioned above, a physical reference surface has a preferred field which inserts a transmission type image sensor (TIS) in inside. As shown in drawing 7, the wafer W attaches the two sensors TIS1 and TIS2 to the reference plate attached to the upper surface of a board table (WT, WTa, or WTb) in the position which counters the outside of a wrap field in diagonal line. This reference plate is made from a material highly stable in the low thermal expansion coefficient dramatically, for example, umber, has the flat reflective upper surface, and may support the mark which it uses in an alignment process. TIS1 and TIS2 are sensors used in order to measure directly the vertical (and level) position of the aerial image of a projection lens. The photodetector which induces the radiation which uses them for each surface for exposure processes in the back near it including an opening is arranged. In order to decide the position of a focal plane, a projection lens projects the image of pattern TIS-M of TIS which provides on mask MA and has ** and dark contrast areas on space. Next, a substrate stage is scanned horizontally (to 2-way [One direction or preferably]), and vertically, and it is made to pass through the space predicted that the opening of TIS has this aerial image. A TIS opening's passage of ** and dark space of the image of a TIS pattern will fluctuate the output of a photodetector. The vertical level whose amplitude photodetector output variation speed is the maximum shows the level with which the image of a TIS pattern has the greatest contrast, therefore shows the flat surface of the optimal focus. The example of this kind of TIS is indicated very in detail to US,4,540,277,B. Instead of TIS, a reflective image sensor (RIS) which is indicated to US,5,144,363,B may also be used.

[0030] Using the surface of TIS as a physical reference surface has the advantage that TIS measurement connects directly the reference plane used for a height map with the focal plane of a projection lens, then a height map can be directly used for it, in order to give height amendment into an exposure process for a wafer stage. This is illustrated to drawing 6, and it shows board table WT positioned under control of Z interferometer in the height decided on the height map, as a wafer surface is located in the right location under projection lens PL.

[0031] This TIS surface may support a reference marker additionally, may detect that position using a TTL (it lets lens pass) aligning system, and may align a board table on a mask. Such an aligning system is indicated to EP-0,467,445A (P-0032), for example. Alignment of each exposed region can also perform an exposed region in the alignment procedure performed in a measurement stage in order to align at the reference marker on a wafer stage, or may be made unnecessary by it. Such a procedure is indicated to EP-0906590A (P-0070), for example.

[0032] Probably, by a production process, it turns out in both the modes of step-and-repeat one and a step

and scan that the mask image projected by projection system PL continues and spreads to a remarkable field not in a single point but in an XY plane. Since wafer height may cover this field and may vary considerably, it is desirable to cover not only a single point but this whole projection area, and to optimize focusing. In the embodiment of this invention, this can be attained, when not only the vertical position of board table WT but inclination (Rx, Ry) of the circumference of the X and a Y-axis controls. The position and range of an exposed region to mean are got to know, and the optima Z and Rx and Ry set point of the board table to each exposure can be beforehand calculated using the height map made by this invention. This omits time required when a wafer is located under a projection lens, in order to level with the known equipment which measures only wafer height, therefore increases a throughput. Using known various mathematical techniques, an interactive process may be used for the optima Z and Rx and Ry set point, and they may calculate it by making into the minimum the focal gap with which it continued and integrated to the whole exposed region (a definition is given as a distance between a wafer surface and an ideal focal plane), i.e., LSQ, (t).

[0033]The further advantage is possible in step and scan mode. In this mode, a projection lens projects some images of a mask pattern on the portion to which an exposed region corresponds. Next, this mask and substrate are synchronously scanned from the object of projection system PL, and the end of an image focal point side to an end, and image formation of all the mask patterns is carried out on all the exposed regions. Although a projection lens is fixed and a mask and a substrate are moved actually, it is often convenient to transpose this process to the image slit which moves on a wafer surface, and to consider it. It is possible to calculate a series of Z which is the beforehand fixed height map and is adjusted to XY scanning path (a scan is usually performed to one way, for example, Y) by this invention, Rx, and Ry set point. This set point of a series of can be optimized by making into the minimum the normal acceleration or tilting which may induce the increase of a throughput, or vibration which is not desirable by an additional standard, for example. Supposing it can give a series of estranged set points, the scanning path over exposure is calculable using a polynomial or a spline conformity procedure.

[0034]Although it means arranging a wafer to an optimal position by Z, Rx, and Ry to the given exposure in this invention, the whole exposed region is covered and wafer height is changed.

Therefore, it may be unable to arrange so that focusing of the wafer may fully be carried out over all the fields.

Such focus spot what is called may produce poor exposure. However, such fault can be beforehand predicted by this invention, and repairing work can be performed. without it carries out the adverse effect of the wafer with faulty peel-off and exposure of a wafer to the further processing -- ***** -- things are made. Instead, the defect who predicted influences only one or few devices on this wafer, but if others are success, they may improve a throughput by flying the exposure which can be predicted that a defective device is made beforehand.

[0035]The further advantage of focus spot detection can be acquired from the analysis of the made height map. When the serious grade from a global wafer surface exists in a wafer height map, this may show the degree of substrate complaint side, or the focal dirt under process influence. The comparison of the wafer height map from some wafers can show the focal dirt by contamination of a board table, or the degree of complaint side. When appearing in the same or, almost same position to the wafer in which focal dirt differs,

this has highest possibility of being generated by substrate holder contamination (what is called "zipper dirt"). From one wafer height map, the height map (topology) from the exposed region (die) to repeat can also be compared. If a big difference arises in a certain die about an average height map, the focal dirt by wafer processing or a board table can be suspected. Instead of comparing a wafer height map, the same comparison can also be performed about the derivation exposure course per die, the focal gap parameters MA and MSD which are explained below, or a move focus. Focus spot can also be detected when a certain die or wafer separates greatly from an average exposure course or a focal gap parameter.

[0036]Before all the analyses described above expose a wafer, they can be conducted, and repairing work like wafer exclusion (influence of processing) or substrate holder cleaning (zipper dirt) can be performed. By these methods, it can localize to the size of the point of measurement of the focus spot level sensor 10. This means the resolution higher than the conventional method of focus spot detection for whether your being Haruka.

[0037]

[Work example 2]The 2nd embodiment of this invention is shown in drawing 8, and it shows only the parts relevant to the following arguments only in an exposure station and a measuring station. This 2nd embodiment uses the leveling principle of this invention explained above with a certain improvement explained below.

[0038]It is shown in the exposure station on the left of drawing 8 that projection lens PL attached to Measurement Division frame MF projects the image of TIS marker TIS-M on mask MA on the sensor TIS attached to wafer table WT. This Measurement Division frame is isolated from transfer of the vibration of this equipment from other parts, and only the passive parts used for detailed Measurement Division and alignment detection are carried on it. This whole Measurement Division frame may be made from a very small material of a coefficient of thermal expansion like umber so that this equipment may also change with the very stable platform of the most sensitive measuring element. The mirrors 34 and 35 are among the parts attached on this Measurement Division frame MF, and measurement beam Z_{IF} of Z interferometer is drawn by the 45-degree mirror 31 attached to the side of wafer table WT at it. In order to guarantee that the motion range of X is covered and Z position of a board table can be measured, the mirrors 34 and 35 have big breadth in the direction of X. In order to guarantee that this Z position can be measured [the range of Y movement], the mirror 31 covers the overall length of a wafer table. Beam generating of the reliance sensor 20a and the receipt parts 21a and 22a which are explained in detail below are attached to Measurement Division frame MF after all.

[0039]In a measuring station (it is the right at drawing 8), the same Measurement Division frame MF supports the mirrors 33 and 32 which achieve the same function as the mirrors 34 and 35 of an exposure station, since the mirrors 32 and 33 also correspond to the required motion range of board table WT -- an exposure station -- completely -- the same -- it has the big breadth of the direction of X. The level sensor 10 containing the beam generating part article 11 and the primary detecting element article 12 is also attached on Measurement Division frame MF. Moreover, it has the same reliance sensor 20b as the reliance sensor 20a of an exposure station intrinsically. It can provide, other measuring devices, for example, alignment module.

[0040]As argued above, using a physical reference surface (also in this embodiment, this is given by the

upper surface of TIS), A wafer height map is related with a wafer stage, and it is made unrelated to a certain local factor like the degree of complaint side of the base plate (stone) BP in which the zero position of two Z interferometers moves it, and a wafer table moves a top. However, since it controls using another Z interferometer which made the wafer height map in the measuring station using Z interferometer, and established the board table position there at the exposure station, A certain difference as a function of the XY position between two Z interferometers may influence the accuracy which arranges a wafer surface to a focal plane. The main factor of these change with the interferometer systems of the kind used by this invention is the degree of complaint side of the mirrors 32, 33, 34, and 35. The 45-degree mirror 31 is attached to wafer table WT, and it moves it with it, when a position replaces between an exposure station and a measuring station. therefore, the degree of complaint side of these mirrors is the same as a measuring station to positioning at an exposure station -- grade influence is carried out and it is fully removed. However, if the mirrors 32, 33, 34, and 35 attached on Measurement Division frame MF stagnate with each interferometer of them, then a difference is shown in the matched pairs 32 and 34 and the surface outline of 33 and 35, the adverse effect of them may be carried out to the vertical-position arrangement accuracy of board table WT.

[0041]The confirmation sensors 20a and 20b are used for initial setting of this equipment, are used if needed periodically after that, and proofread the difference between Z interferometers at a measuring station and an exposure station. These confirmation sensors are sensors which can measure the vertical position of the upper surface of a wafer at one or more points when scanning a board table under it. Although the reliance sensors 20a and 20b can make a design the same as the level sensor 10, since it is not necessary to do them so and only; and setting out are used for them not with a production wafer but with a reference wafer (to and rare recalibration), their design basis is not troublesome and they can design a simple sensor using this. On the contrary, that projection lens PL exists in an exposure station needs to restrict the physical location which can be used for a confirmation sensor at the station, and it also needs to take this into consideration to a design or selection of each confirmation sensor. Since the proofreading using a confirmation sensor influences the quality of all exposure, high degree of accuracy is required of them.

[0042]A board table is loaded with a reference wafer in the proofreading process using a confirmation sensor. As for this reference wafer, it is preferred that it is a naked silicon wafer. although some flat demands do not have it from the Si wafer of the usual nakedness -- the surface finish (at point of reflectance) -- optimizing to the reliance sensor of these is preferred. It is preferred to grind so that this reference wafer may make that reflectance the maximum and the degree of complaint side may be made into the minimum in the preferred embodiment of this invention.

[0043]The partial height map (it usually passes and is related to a physical reference surface) of a reference wafer is made from a calibration procedure in a measuring station not using the level sensor 10 but using the confirmation sensor 20b. This is performed by the same method as the level sensor 10, arranges; physical reference surface (TIS) at the zero point of a reliance sensor, makes Z interferometer zero, then, scans a wafer under a reliance sensor, and makes a height map from the difference between reading of a confirmation sensor and Z interferometer. A height map is made from the same point as the height map of a measuring station also at an exposure station using the reliance sensor 20a. To this proofreading, the height

map does not need to scan a wafer thoroughly and only needs to cover the strip corresponding to movement of Z interferometer beam on the; mirror 32–35. (If an order which makes the map of these is stability while a wafer performs both on a board table, it is not important.)

[0044] Probably, they were produced according to the difference between the measurement systems used in order to make them, when these maps had a difference among them, since they expressed the same wafer. Two reliance sensors are static, then normalization of two height maps instead of positional dependence and/or subtraction of an offset can remove the influence on those height maps. If there is a difference which remains, it is positional dependence, can lengthen two height maps from each other, and can make the compensation table (mirror map) which relates an exposure station Z interferometer with a measuring station Z interferometer. It is possible that these compensation tables are the results of the difference between the mirrors 33, 35, and 32 attached to Measurement Division frame MF, and 34, Then, it can use in order to amend one of the Z interferometers used in order to be able to apply to the wafer height map made from the production process or to make a map, or in order to position a board table during exposure. The difference of Z position produced the degree of complaint side of the mirror of each interferometer systems by a precise structure especially the Measurement Division frame mirror, and board table mirror of Z interferometer may also be an inclination dependency in one or more flexibility (R_x , R_y , R_z). In order to abolish this inclination dependency, the compensation table (mirror map) in which it may be necessity in which making some height maps in the wafer stage of various different inclinations using a reliance sensor, and a large number differ if needed can be derived.

[0045] Since the principle of off-axis leveling was explained, the further improvement of some used in the 2nd embodiment and the method to the production process to incorporate are explained shortly. Drawing 9 and drawing 10 show the process performed at a measuring station and an exposure station, respectively. In the lithography device which uses two wafer tables, one table performs the process of drawing 9, and on the other hand, the 2nd table performs the process of drawing 10 simultaneously, before exchanging them. By the following explanation, the "life" of a single wafer continues until it goes and returns from a measuring station (drawing 9) to an exposure station (drawing 10).

[0046] It loads with the wafer applied to the process S1 of drawing 9 by **** and a photosensitive resist on board table WT. this generally has a board table out of the range of interferometer–systems IF. It should be cautious of it carrying out at a charge station other than a measuring station. Process S2 of moving this wafer table into the capturing range of one or more position detecting devices (PSD) so that it can perform initial rough zero setting an interferometer instrumentation system. Detailed initialization / zero setting interferometer systems continue by the process S3 and S4 after this initial rough zero doubling. It appoints a reference plane (it fixed to the wafer table) including the level sensor measurement ("LS" shows) on a physical reference surface (two or more), and these two processes measure a wafer height map about it. Two alignment measurement ("AA" shows) is performed about the marker located on the same physical reference surface, and the level reference position fixed to the wafer table is defined. These measurement by S3 and S4 carries out zero doubling of these interferometer systems effectively with all the flexibility.

[0047] The next process in this leveling procedure is S5 called a global-area level outline (GLS). In this process explained in more detail below, the initial scan by the level sensor of wafer prehension and a wafer is performed, and the height in the greater part of that point that the height of that whole, an inclination, and

a next detailed scan frequent this wafer is decided. This information enables it to decide the board table course for a wafer height map scan.

[0048]Global-area alignment of a wafer is performed at the process S6. At least two alignment markers on a wafer are measured (W1 and W2), and it means that those XY positions were decided about the reference marker on a TIS standard. This determines the grade (Rz) which rotates a wafer horizontally about a scanning direction (y), and like, since [which performs a wafer height map scan in parallel with an exposed region axis (that is, "an exposed region top is gone straight on")] rotation of a wafer can be amended, it performs it.

[0049]Then, this leveling procedure continues measurement required for processing dependence amendment (PDC). Processing dependence amendment is required of a form with a level sensor, and is explained below.

[0050]A wafer height map must be made every, whenever it exposes a wafer. If the wafer has already received one or more down stream processing, this surface layer may also have the topology showing not already pure polished silicon but the structure already made on this wafer, or the already made form. A different surface layer and structure may influence reading of a level sensor, and the linearity may be changed especially. ***** [influence / these influences may be based on the diffraction operation produced according to a surface structure, for example, may be based on the wavelength dependency of surface reflectance, and] whenever this level sensor is optical. In order to opt for required processing dependence amendment, board table WT is set as a different vertical position of some covering the linearity or the linearization range of the level sensor 10, and an exposed region or a die is operated under this level sensor. the physical distance between wafer height, i.e., a wafer surface, and a reference plane should not change in the vertical position of a board table --; -- : $Z_{\text{WAFER}} = Z_{\text{LS}} - Z_{\text{IF}}$ obtained when it lengthens the measured value of a level sensor and Z interferometer. Therefore, if the value which Z_{WAFER} determined does not change in the vertical position of a board table, this means that either a level sensor or Z interferometer and both are not linearity, or it is not a ** scale. Since Z interferometer looks at the mirror on a wafer table and the Measurement Division frame, when it is thought that it is linearity and; actuality and the amendment for which it once opted by use of the confirmation sensor at least are applied, it is linearity from accuracy required for a wafer map at an altitude. Therefore, if a wafer height value has a difference, it will be assumed that it was produced from the nonlinearity or the scale error of the level sensor. The output of this level sensor can be amended using the knowledge of reading of a level sensor when they and they are observed. In the embodiment of this level sensor suitable now, although simple gain correcting was enough, it turned out that still more complicated amendment may be necessity at other sensors.

[0051]If it has the exposed region where the wafer which should be processed has received another processing on it, it will opt for processing dependence amendment to the exposed region of each different **** form on this wafer. On the contrary, what is necessary is just to measure processing dependence amendment to the exposed region of 1 time various kinds per batch, if the batch of the wafer which has the exposed region which received the same or similar processing should be exposed. Then, the amendment is [every] applicable whenever it makes the height map of the kind of exposed region from a batch.

[0052]In many IC manufactures, just before loading a lithography device with a wafer, a photosensitive resist is attached to it. When it loads with a wafer and clamps in a proper place for the Reason of this or others, it

may be a different temperature from a board table. Since the wafer is clamped very firmly using vacuum suction when a wafer gets cold to the same temperature as a board table (or it got warm), heat stress may arise. These may produce distortion which is not desirable as for a wafer. The thermal balance is attained [by] when the processes S2 thru/or S7 finish. Therefore, at the process S8, the vacuum clamp to the board table of a wafer is released, the heat stress of a wafer is loosened, and then it re-applies. Although this relaxation may produce a small change in the position and/or inclination of a wafer, the process S2 thru/or S4 are unrelated to a wafer, and since S5 and S6 are only coarse measurement, these are permissible. Since it is not measurement of a wafer but proofreading of a level sensor, change of the wafer position in this stage does not influence processing dependence amendment.

[0053]It is not again released until it completes an exposure process for a vacuum henceforth after re-application and performs Z map by process S9. The scan required for this Z map must measure the height of sufficient point so that a wafer can be arranged in desired accuracy during exposure. The measured point may be important also for covering the actual field which should expose a wafer,; seal attachment lane and what is called a rat may bite, and the measurement covering a non-exposed region like a crack may produce the result which invites misunderstanding. Therefore, a height map creation scan must be optimized to the specific pattern of the exposed region on the wafer at hand, and explains this below to; in more detail.

[0054]Once Z map is completed, after performing precedence alignment measurement and the process S10, board tables will be exchanged to an exposed position at the process S11. In this precedence alignment process, the position of many alignment markers on a wafer over the reference marker located on the TIS standard (physical reference surface) fixed to the board table is determined correctly. This process is not explained here any more without relation to this invention in particular.

[0055]In a replacement procedure, the board table which supports the wafer which made the height map arrives at an exposure station. The process S13 of drawing 10. A coarse position decision of a board table is made at the process S14, and if required, mask table MT is loaded with new mask MA. Process S15. This mask change process may be performed simultaneously with board table exchange, or may be begun at least. Once a proper place has a mask and it stops by performing coarse position determination and the process S14, the 1st TIS scan will be performed using sensor TIS1 at the process S16. As explained above, this TIS scan of the board table in which this TIS is located in the aerial image focus of a projection lens is vertical, and a horizontal position is measured and it brings about "refer to the focal plane." Since the height map made from process S9 of drawing 9 is connected with the physical surface in which TIS is located, the direct lead of the vertical position of a board table required in order to establish a wafer surface in a focal plane to another exposed region is carried out. The 2nd TIS scan and the process S17 are also performed using sensor TIS2, and the 2nd point for referring to a focal plane is acquired.

[0056]If a TIS scan is once completed and a focal plane is determined, the exposure process S18 will be performed after system proofreading (for example, adjustment for amending the lens heating effect) required for the arbitration in the process S19. This exposure process is generally accompanied by exposure of two or more exposed regions using one or more masks. When using two or more masks, after the mask exchange S20, one TIS scan S17 can be repeated and focal plane change can be updated. Among all the exposure, the system proofreading process S19 may also be repeated partly. It exchanges at the board

table and the process S13 of supporting the wafer which received the processes S1 thru/or S10 of drawing 9 for the board table which supports the exposed wafer after the end of all the exposure between them. The exposed wafer is taken out so that the board table which supports the exposed wafer may be moved to a charge station, and it can load with a new wafer and this cycle can be resumed.

[0057]In order to explain the wafer height map creation scan of process S9 of drawing 9, drawing 11 shows the example of the pattern of various form and the exposed region C of a size arranged on a wafer so that silicon area may be used best. A triangular free space is inevitably left behind to the general target which seal attachment rain SL separates the different exposed region C, and "rat bites, and is known as crack" between a rectangle exposed region and the curvilinear edge of a wafer. Once all the production processes complete these seal attachment lanes (a different device is separated like), will just be going to cut this wafer, and a certain cutting technology, it may be required that all the seal attachment lanes of one way should straddle the whole width of a wafer --; -- in that case, if this equipment should be used in step and scan mode, it is convenient to turn these wafer width seal attachment lanes of all the in parallel with a scanning direction (for example, the direction of Y). After these seal attachment lanes and a rat may bite, and a crack may not be exposed, then this wafer receives some down stream processing or covering of a layer, they may have the dramatically different height and surface characteristic from the exposed region C. Therefore, it is important that height measurement of these fields that are due to be exposed and that are not is disregarded.

[0058]In order to measure height simultaneously at nine points (field), the linearity array of nine optical spot arranged at right angles to a scanning direction is used for the embodiment of a level sensor suitable now, for example. (It should be cautious of the ability to interpolate in order to give Z position data in which a board table corresponds by the array of the level sensor point that Z interferometer data also corresponds.) The array of this spot is sufficient size to cover the width of the widest exposure area which can be exposed with this equipment.

[0059]as the central spot of this array passes along a suitable scanning mode along the intermediate cable of each sequence of an exposed region now, it is scanning the array of a spot in the meandering course 50 --; -- this intermediate cable is equivalent to the intermediate cable of the slit illuminated in this exposure process. Thus, the made data can be connected an exposure scan and directly by the minimum rearrangement or calculation. Since this method scans towards the same position on the mirror 31 which attached Z interferometer beam to the board table at both a measuring station and an exposure station, it loses a part of mirror complaint side degree influence. If the sequence of a die is narrower than the array of the spot of a level sensor, the data obtained from the spot which is not into an exposed region thoroughly will be disregarded. It may be possible to adjust in other embodiments of a level sensor, so that the width of the array of a spot may be doubled with the width of an exposed region.

[0060]Supposing the center line of the exposed region with a wafer has shifted in the direction more nearly vertical to a scanning direction than the remaining center lines, it may be advantageous to use a correction scanning mode. This situation is shown in drawing 12 and it shows that the center line of the die E of one line has shifted from the remaining dies D. In such a case, a map can be more nearly promptly made from small acceleration to a board table by scanning two meandering courses. One course shown in drawing 12 by 52 covers 1 set of exposed regions D, and other courses shown by 53 cover other fields E. Of course, other

arrangement of an exposed region may require the further correction of a scanning mode.

[0061] Although it is being, when it has the linearity or the linearization range to which the level sensor was restricted, board table WT must be scanned in the vertical position which carries in a wafer surface within the limits of it under it. By the closed feedback loop to the board table positioning system of reading of a level sensor, although it is easy, adjusting the vertical position of board table WT, in order to maintain a wafer surface at this linearity or linearization within the limits once it finds a wafer surface, When a level sensor moves on an exposed region from the exterior of a wafer at the beginning, it is not so easy to find a wafer surface. There are some of such ON points, the reference number 51 and an arrow show on the meandering course 50 of drawing 11, and a problem is compounded with a meandering course.

[0062] In order to find a wafer surface at the ON point 51, it is possible to provide a prehension spot before the main level sensor spot array. Next, a reflection of this prehension spot on a wafer is led to the detector which has a capturing range wider than the case of main spot. However, this requires the prehension spot of the both sides (front/after) of additional hardware: main spot, or restriction of the scan only to one direction. The alternative which does not necessarily require additional hardware is stopping a board table near [an ON point] each, and performing wafer prehension, and measuring a wafer surface in the linearity or the linearization range of a level sensor, and approximating a wafer surface position at this ON point. However, this makes this measurement procedure quite late, and may be a result which is not desirable from a point of a throughput.

[0063] In this embodiment of this invention, after catching a wafer surface for these problems, it avoids by performing an above-mentioned global-area level contour scanning (process S5 of drawing 9). This global-area level contour scanning is further explained with reference to drawing 13.

[0064] For this global-area level contour scanning, as a point with sufficient convenience in the exposed region C to the beginning (a thing near an edge is preferred) is under a single prehension spot and main spot of a level sensor (spot array), a board table is arranged. For example, by scanning a board table, a wafer surface is found, and a board table is scanned so that the central spot 41 may next cross the surrounding course 60 inside the circumference of all the exposed regions, until it catches a wafer surface and comes to linearity [of main spot], or linearization within the limits. This prehension procedure is explained in detail below. Measurement of wafer surface height is performed in a regular position around this scan. Of course, the central spot can also perform measurement from these spots as well as this central spot, when other spots of this array hit on a wafer (exposed region). However, measurement should not be performed from a spot which hits out of an exposed region. When; which is the course which approaches considerably and follows an edge of an exposed region, and which would, however a smoother course may also be used and an exposed region is well stuck for a wafer especially, the circular course 61 is enough as the global-area level outline course 60, and it may be convenience more, so that it may illustrate. Data of measurement which could allocate this global-area level outline as a circle which a rat bites and passes along a crack top, a rat bit in that case and did not perform measurement on a crack, or a rat blew and was performed on a crack is disregarded for global-area height of a wafer, and calculation of an inclination.

[0065] The data collected by the global-area level contour scanning is used for the two purpose. The data relevant to wafer height near [ON point 51 (refer to drawing 11)] the height map creation scan which should be performed [1st] behind, It is used in order to predict the wafer height in the ON point 51, and

during a map creation scan, in order to put a wafer surface position into linearity or linearization level sensor within the limits, a board table is made to be made into right height. When the most, in particular in order to need only few data points for the purpose but to enable prediction of wafer height exact enough by interpolation or extrapolation moreover, it does not need to be close to an ON point. Since this level sensor has an array of a spot which needs to be made all (preferably) linearity or linearization within the limits in the direction of X, it is also desirable to get to know the local Ry inclination in the ON point 51 to a height map creation scan. If a global-area level contour scanning is parallel to the direction of Y near [which] an ON point or near in parallel, Ry inclination cannot be correctly decided using the data obtained only from the single spot. When using the level sensor which has an array of the measurement spot estranged in the direction of X so that it may explain below, a local Ry inclination can be decided using the data from two or more spots. Of course, if a part of array comes outside an exposed region, the data from the spot in the field will be chosen.

[0066]The 2nd use of global-area level contour data is deciding a global area or an average, height, and an inclination (circumference of biaxial) for all the wafers. This is performed by a known mathematical technique, for example, a least square method, in order to decide the flat surface which suits in collected wafer height data best. If this global-area inclination (a "wedge" is sometimes called) is larger than a predetermined value, this may show enough that a charger's order is not right. In that case, it can even perform eliminating, supposing it can take out and re-load with a wafer for a retry and continues failing. Using this global-area height and tilt information, in order to decide correctly the spaced relationship to the reference marker on a substrate stage of the alignment marker on a wafer, the precedence alignment sensor used at the process S10 of drawing 9 is converged. This precedence alignment sensor and process are indicated in detail to WO98 / 39689 (P-0070).

[0067]During a wafer map scan, the level sensor 10 provides the continuation Z and Ry feedback signal to a board table, and maintains the level sensor 10 in the linearity or the linearization range. if -- this feedback loop -- stopping (the level sensor 10 does not supply the number of the rights) -- a table is controlled by following the course corresponding to a global-area wafer wedge (Z outline by the global area Rx).

[0068]The embodiment of the level sensor 10 suitable now is shown in drawing 14, and it explains below additionally with reference to drawing 14 A thru/or drawing 14 G which shows the mode of operation of this sensor.

[0069]The level sensor 10 is the wafer W (or it swerves, when measuring the vertical position of a physical reference plane, and) about measurement beam b_{LS} . Or the detection brunch 12 which depends on the vertical position of the beam generating brunch 11 turned on other reflectors and a wafer surface and which measures the position of the reflected beam is included.

[0070]In this beam generating brunch, a measurement beam is generated with the light source 111, it is generated by that light source in luminescence, the array of a laser diode, or others, and it may be sent to "illuminator" 111 by an optical fiber. As for the beam which the light source 111 takes out, it is preferred that a wide band wavelength, for example, 600 thru/or 1050 nm, is included so that the wavelength dependency of the cross protection from a wafer surface may be especially averaged after some ends of down stream processing. The illumination-light study system 112 collects the lights of a lens and a mirror which may also include some suitable combination and the light source 111 gives off, and illuminates the

projection lattice 113 uniformly. The projection lattice 113 is shown in drawing 14 A in detail, and in order to make the separate spot of /each, it comprises the opening 113b of the addition which makes a prehension spot before these main detection spot arrays on the long and slender lattice 113a which may make a grid line parallel and may divide it into the axis, and a wafer. The cycle of this lattice may be decided in part with the accuracy which should measure this wafer surface position, for example, about 30 micrometers of it may be sufficient. Also to which axis of coordinates, to the circumference of that optic axis, it rotates slightly, and the grid line projected on a wafer arranges this projection lattice, and avoids interference with the structure on the wafer which is along x or a y direction by it so that in parallel. The projection lens 114 is telecentric system which projects the image of the projection lattice 113 on the wafer W. comprising only a reflected-light study element or it intrinsically so that the projection lens 114 may make the chromatic aberration of the projected image the minimum or may avoid it -- desirable --; -- the projection beam of it is a broadband.

It is because they cannot be easily removed or compensated with a dioptric system.

Projection beam b_{LS} is taken in and out of the projection lens 114 using the folded mirrors 115 and 116, and arrangement with the sufficient convenience of the parts of this beam generating brunch is enabled.

[0071]Projection beam b_{LS} enters into a wafer at an angle of [quite big / α] the range of 60 degrees thru/or 80 degrees as opposed to a normal, and is reflected in the detection brunch 12. If the position of wafer surface WS moves only distance δh to position WS' as shown in drawing 14 B, only distance 2 and $\delta h \sin(\alpha)$ move reflective beam r' to the beam r before movement of a wafer surface. By drawing 14 B showing the appearance of the image on a wafer surface, since; incidence angle is large, this image spreads at right angles to a grid line.

[0072]Reflective beams are collected according to the detecting optical system 121, it converges on the detection lattice 126, and the lattice is a duplicate of the projection lattice 113 intrinsically.

It subdivides so that it may correspond to this spot array pattern.

The detecting optical systems 121 are the projection optical system 114 and the complementation directly. In order to make a chromatic aberration into the minimum, only a reflected-light study element or it is comprised intrinsically.

Convenience may improve arrangement of parts using the folded mirrors 122 and 123 again. Between the detecting optical system 121 and the detection lattice 126, the linearity light polarizer 124 which polarizes light at 45 degrees, and the doubly refracting crystal 125 which makes a gap vertical to a grid line in a size equal to the lattice cycle between vertical-polarized-light ingredients horizontally [this light] are located. the beam in the detection lattice 126 in case drawing 14 C does not have this doubly refracting crystal is shown --; -- it is a series of light band regions and dark band regions which carry out alternation, and 45 degrees of light band regions polarize. The doubly refracting crystal 125 is level, and changes a vertical-polarized-light state so that the light band region of a horizontal-polarized-light ingredient may fill the dark band region of a vertical-polarized-light ingredient. Therefore, as shown in drawing 14 D, although the illumination in the detection lattice 126 is uniform gray, it has a strip of the polarization condition which carries out alternation. The detection lattice 126 covers the half of one polarization condition, for example, a vertical light band region, and the half of other states, and drawing 14 E blockades, when the detection lattice 126 which depends on the vertical position of a wafer surface and which was put on this pattern is

shown and; wafer is in a nominal zero vertical position.

[0073]The lights which passed the detection lattice 126 are collected according to the modulation optical system 127, and it converges on the detector 128. A modulation optical system contains the polarization modulation equipment driven with an alternating signal with a frequency of about 50 kHz so that it may let two polarization conditions pass by turns. Therefore, the image which the detector 128 looks at carries out the alternation of between two states shown in drawing 14 F. The detector 128 is divided into the field of a large number corresponding to the array of the spot which should measure height. The output of a field with the detector 128 is shown in drawing 14 G. It is an alternating signal with a cycle equal to it of a modulation optical system.

The amplitude of this vibration shows the alignment grade of the reflected figure of the projection lattice to a detection lattice top, therefore the vertical position of a wafer surface.

As mentioned above, if a wafer surface is in a nominal zero position, the detection lattice 126 will have the equal intensity which intercepted the half of a vertical-polarized-light state, and the half of a horizontal-polarized-light state, then was measured, and the amplitude of the vibrating signal output by a detector area will be zero. If the vertical position of a wafer surface moves from this zero position, the detection lattice 126 will begin to prevent many of through and vertical-polarized-light zones for many of horizontal-polarized-light zones. Then, the amplitude of vibration will increase. The amplitude of this vibration which is a measure of the vertical position of a wafer surface is not related to a direct radiation form by NANOMETA in the vertical position of a wafer surface. However, by measuring the fixed height of the surface of a naked silicon wafer in a different vertical position of the versatility of a board table using Z interferometer and the unproofread level sensor 10 which proofread the amendment table or the formula, It can decide easily by initial setting (and if required, recalibration was carried out periodically) of this equipment.

[0074]A synchronous bus is formed in order to guarantee having performed measurement of the level sensor and Z interferometer simultaneously. This synchronous bus tells the clock signal of the very stable frequency which the master clock of this equipment generated. Both a level sensor and Z interferometer are connected to this synchronous bus, and the sampling point of those detectors is decided using the clock signal from this bus.

[0075]As the prehension spot 113b which passed the projection lattice 113 passes along a detection lattice and it shows drawing 15 A there, two 131 and 133 are set up highly and one 132 enters into three different detection areas set up low. The output from this low detection area is lengthened from a height detection field to an output. When a wafer surface is in a zero position, these prehension spot detector areas are allocated so that the output which the prehension spot hit high and a low detection area equally, and lengthened to it may be zero. When it separates from a zero position, the increase of the size of the output which the prehension spot hit more mostly [one of the detection areas] than others, and lengthened, and its mark show whether a wafer is too expensive or it is too low. The dependency to board table position Z_{IF} of lengthened detector output d_{cap} is shown in drawing 15. This form of a detector output makes possible a zero capturing method quicker than the conventional servo feedback. When according to this method of having improved called "move-until" the wafer surface of a prehension spot detector is too high or past [the low one] is shown, Z position actuator of a board table directs to move this stage in the suitable direction, in order to

put this wafer surface into linearity [of the main level sensor array], or linearization within the limits. Movement of this wafer stage continues until the output of a prehension spot detector passes trigger level t_n or t_p , and according to that direction, it moves it. If a trigger level is crossed, the control device of this equipment will be made to come out of a command to Z position actuator, and brake procedure will be begun. These trigger levels are set up this stage move to a zero position, or approach during the time required in order to apply brakes to this response time and stage movement. Then, this stage can be brought to a zero position under control of the more exact main level sensor spot. It is not necessary to decide these trigger points according to the kinetics of this stage, and to estrange them symmetrically with the surroundings of a null detector output. Without requiring a linear measurement system, the this "move-until" control system enables quick and strong zero prehension, and can use it for other situations.

[0076]The level sensor explained above can be further optimized, in order to improve the performance. An improvement of the accuracy of the scanning (Y) direction can be made by suitable signal filtering, and this may be fitted to the specific process layer seen on the wafer processed selectively. The improvement (as opposed to a specific process layer) of an addition of all the directions, By changing the illumination-light study system 112 (in order to adjust the homogeneity of the illumination light on the projection lattice 113, and/or angular distribution), It may obtain changing the projection lattice 113 or by adjusting a detection system (the size, the position and/or the angular resolution, and the number of detectors of a detector).

[0077]The form of the reliance sensors 20a and 20b suitable now is shown in drawing 16 and drawing 17. The beam generating brunch 21 contains the light source 211 (for example, a solid-state laser diode or a super luminescent diode) which gives off the light of the limited bandwidth. It is convenient for it to be separated and located from the Measurement Division frame, and to bring the output to a desired point by the optical fiber 212. This light is outputted from the fiber termination machine 213, and it turns on the beam splitter 215 according to the collimator optical system 214. The beam splitters 215 are two parallel measurement beams. [External character 1]

b c 0 1 お よ び b c 0 2

Structure and they are converged according to the tele centric projection optical system 216, in order to illuminate each spot 23 on the wafer W uniformly. Since the bandwidth of the measurement beam of this reliance sensor is restricted, a refractility element can be used for the projection optical system 216 with sufficient convenience. The beams by which the detecting optical system 221 was reflected are collected, and it converges on the edge of the detection prism 222 located between the detectors 223 and 224 and the detecting optical system 221 in them. As shown in drawing 17 which is a side view of the detection prism 222 and the detector 223, a measurement beam enters into the back of the detection prism 222, and comes out from the inclined planes 222a and 222b. The detector 223 is arranged so that the two detector elements 223a and 223b may be comprised, the light which comes out from the field 222a of the detection prism 222 may reach the detector element 223a and the light which comes out from the field 222b may reach the detector element 223b. The detector 224 is the same. The output of the detector elements 223a and 223b is evaluated and subtracted by intensity. When a wafer surface is in a zero position, these measurement beams turn a hit and equivalent weight of lights to the detector elements 223a and 223b symmetrically on the field 222a of the detection prism 222, and 222b. Next, the output which these produced the equivalent output, then was subtracted becomes zero. If a wafer surface moves from this zero position, the position of

the reflected beam will change proportionally the output which hit more mostly [one of taking up and down and the fields 222a and 222b] than others, and resulted in turning much light by each detector element, then was subtracted. The inclination of a wafer can be decided by comparison of the output of the detectors 223 and 224.

[0078] This arrangement brings about the easy and strong height and level detector which are the 2nd embodiment of this invention and can be used as a confirmation sensor for other uses. This confirmation sensor mainly means, measurement, initial setting of Z interferometer of an exposure station, and periodical, for example, the recalibration of a month unit. However, the confirmation sensor explained above has a capturing range wider than TIS used for a precise determination of the position of the focal plane of projection lens PL to board table WT, and a quick response. Therefore, when exchanging board tables to an exposure station first, the check confirmation sensor 20a can be advantageously used, in order to make a coarse decision of the vertical position of TIS. It connects with the best focal matching position which measured previously the height measured with this confirmation sensor, and it uses in order to predict the starting point and range for the TIS scan near the position which this best focal plane expects. This can make short, therefore quick the TIS scan explained above, and means improving a throughput.

[0079] The beam splitter 215 which can be used for these confirmation sensors is shown in drawing 18. A beam splitter comprises much prism of equal thickness desirable from the same glass. A basic motion principle is explained using the beam splitter which comprises the three prism 51, 52, and 53. As for the prism 51, a section is a trapezoid and the input beam 54 enters near one side of the upper surface 55. As for the position of the input beam 54, it hits this upper surface 55 and the one side face 56 of the 1st 45-degree prism 51. The 2nd prism 52 is joined by the side 56 of the 1st prism 51, the portion (this example half) of a request of this input beam carries out Naori into the 2nd prism 52, and forms the beam 57, and on the other hand, the remainder applies this joint so that it may reflect horizontally within the 1st prism 51 and the beam 58 may be formed. It hits the 2nd side 59 parallel to the 1st side 56 of the prism, and is reflected caudad, and the beam 58 reflected by the 1st prism 51 comes out of the undersurface of the 1st prism 51, and passes along the upper surface and the bottom of the 3rd prism 53 parallel to the upper surface of the 1st prism 51. The 2nd side 59 may be applied if needed, in order to guarantee the total internal reflection of the beam 58. Internal reflection of the beam 57 included in the 2nd prism 52 is carried out by two parallel surfaces of the 2nd prism 52 vertical to the side 56 of the 1st prism 51, and it comes out of the upper surface 55 of the 1st prism 51, and the parallel bottom of the 2nd prism 52. It separates and the beams 57 and 58 are outputted by it, although it is parallel. The separation between the beams 57 and 58 is decided by the size of the prism 51 and 52. The prism 53 is formed in order to equate the light path length of both beams so that the beam 57 and the image formation optical system for 58 can be made the same. Although the prism 53 also supports the prism 52 like a graphic display, this [its] may be unnecessary for a certain use. In order to improve a reflection of the beam 57 in the field where the prism 52 and 53 touches, it may leave a void or a suitable film may be provided.

[0080] The beam splitter 50 is easy, strong, and easy to make. It brings about an output beam with equal light path length by parallel (as opposed to the conventional cube beam splitter bringing about a straight beam). this parting plane -- a polarization case index -- or it can do not right [that] and, in the case of the latter, a request can divide input beam intensity uniformly or unequally.

[0081]It is the feature of the level explained above, a reliance sensor, and other optical height sensors that it is insensible in the inclination of the wafer stage of the circumference of an axis vertical to the Z direction defined by intersection of the focal plane of the measurement spot of wafer surface WS and the level sensor 10. This is based on the fact that these sensors cover the field of the measurement spot extrapolated to the focus axis of a spot, and measure height. This inclination insensible nature can be used in order to proofread Z interferometer and a photosensor to the more nearly mutual one in an XY plane. A similar procedure can be used for a confirmation sensor or other similar photosensors although the procedure for such composition is explained with reference to drawing 19 and a level sensor.

[0082]It can be set up add rotation to the surroundings of the axis as which the XY plane chose the positioning system of the board table using Z actuator which was combined with the multiaxial interferometer systems in which this Z interferometer is that part, and was estranged. In order to align this Z interferometric measurement position with level sensor measurement spot, using this positioning system, it passes along this Z interferometric measurement position, and this stage is rotated to the circumference of an axis parallel to a Y-axis, for example. Z position of this table measured with Z interferometer does not continue not changing during this inclination. If a level sensor and Z interferometer are aligned correctly, a wafer surface position will not continue not changing, either. However, if a level sensor measuring point inclines toward the position which only quantity ΔX has shifted from Z interferometer position, and shows board table WT with an imaginary line with the figure as shown in drawing 19, change ΔW_{LS} will be produced in a level sensor output. Therefore, position gap ΔX and position gap ΔY of the direction of Y can be promptly decided by detecting change of the level sensor output by the inclination of the circumference of two desirable vertical axes which pass Z interferometer position. Then, the parameter of these interferometer systems or the level sensor 10 can be adjusted so that it may guarantee that this interferometric measurement position counters correctly with a level sensor measuring point.

[0083]When a level sensor uses the array of measurement spot, it always should not be guaranteed that these spots have aligned correctly. Therefore, it can opt for a position gap of each spot of the nominal position about Z interferometer position using the above-mentioned technique. Next, a height map or a level sensor output can be amended using this information.

[0084]

[Work example 3]The 3rd embodiment is the same as the embodiment except for using the leveling principle of the 1st embodiment, then explaining below. The hardware of the 2nd embodiment and improvement which were explained above may also be used for this 3rd embodiment. However, the method improved for optimization of an exposure course is used for this 3rd embodiment. This is explained with reference to drawing 20 below.

[0085]As argued above, a substrate stage is immobilization, and what is actually moved is a wafer, but it is well appropriate to convenience to think that an exposure slit image moves. The following explanation is given from this viewpoint.

[0086]Drawing 20 shows the notation used below. Although slit image SI is separated from a wafer surface and drawn by drawing 20 for plainness, it should be cautious of it being guaranteeing the focal plane of the purpose of this optimization procedure of a slit image corresponding with a wafer surface as much as possible during exposure. If the surface considers the one-dimensional wafer and slit image SI which are

defined by $w(y)$, moving average (temporality) focal gap $MA(y)$ corresponding to the coordinates on this wafer is calculable as follows. : [Mathematical formula 2]

$$MA(y) = \frac{1}{s} \int_{-\frac{s}{2}}^{\frac{s}{2}} [w(y) - [z(y+v) - vR_x(y+v)]] dv \quad (2)$$

However, this integration is performed by covering the slit size s of a scanning direction, and integrand $w(y) - [z(y+v) - vR_x(y+v)]$ is a focusing error on the point of a certain instantaneous wafer. Similarly, the move standard deviation to the point on a wafer can be defined as follows. : [Mathematical formula 3]

$$MSD^2(y) = \frac{1}{s} \int_{-\frac{s}{2}}^{\frac{s}{2}} [w(y) - [z(y+v) - vR_x(y+v)] - MA(y)]^2 dv \quad (3)$$

It is a focal gap time jitter under actual exposure of the point on a wafer. In order to make the flat surface of an exposure slit image, and the difference between wafers into the minimum, a definition is given as follows using a secondary focal gap clause. : [Mathematical formula 4]

$$MF^2(y) = \frac{1}{s} \int_{-\frac{s}{2}}^{\frac{s}{2}} (w(y) - [z(y+v) - vR_x(y+v)])^2 dv \quad (4)$$

$MF(y)$ is called a move focus here. Also as follows, $MF(y)$ can be written by the clause of $MA(y)$ and $MSD(y)$. : [Mathematical formula 5]

$$MF^2(y) = MA^2(y) + MSD^2(y) \quad (5)$$

[0087] This is optimization of an exposure course, and the minimization of a move focus covering an exposed region, and, unlike simple least square method optimization of the 1st embodiment that disregards time, therefore scanning integration, means taking both a moving average and move standard deviation into consideration. The formula (3) and (4) applies $R_y(t)$ dependency, and can extend it to two dimensions easily by integrating with MF about X from $-W/2$ to $+W/2$, however W is the width of the slit of the direction of X . In order to calculate this optimization, it is convenient to use frequency domain expression. Calculation in a frequency domain filters high frequency change of a set point which will bring a result which produces some or substrate stage acceleration superfluous at all the flexibility, and is also removed so that an exposure course may be optimized to the performance of a board table positioning system.

[0088] although it assumed that the optimal focus of an exposure slit image was in agreement with a flat surface in the upper argument --; -- this is not necessarily so --; -- in practice, the optimal focus may be in arbitrary fields and may produce what is called a focal plane deviation (FPD). In order to make the outline of the field on an exposure slit region the focal map $f(x, y)$, supposing it is able to measure or calculate using TIS, the made data or the formula can be added to the upper formula so that wafer movement may be optimized to actual optimum top ****.

[0089] It can finish with better focusing and the smoother substrate stage course over a scanning system, and the optimization technique of this 3rd embodiment increases a throughput and a yield.

[0090]

[Work example 4] In the 4th embodiment, it has the additional feature for negating the error which a level sensor may produce by interference between the beams which were refracted into the beam and regist

layer which were reflected by the upper surface of the resist layer, and were reflected by the bottom by measurement of the wafer surface position. Otherwise, this 4th embodiment may be the same as any of the 1st thru/or the 3rd embodiment which were explained above they are.

[0091]Of course, interference of the beam reflected from the above-mentioned upper surface and the bottom depends for the optical wavelength and the incidence angle of a measurement beam on resist characteristics and the wafer surface characteristic greatly. In order that the source of wide band light and a detector may average such single wavelength interference, it is used now. If it measures by the method which carried out spectral resolution of the wafer surface position and it performs separate measurement to much wavelength of a broadband measurement beam, an improvement of this equalization principle is realizable. In order to attain this, it is required to make the wavelength (color) system divided into measurement of the wafer surface position in time or spatially. This needs the following change for the measurement principle of a level sensor.

[0092]The 1st possible change to a level sensor is being able to generate selectively and replacing the optical beam of a wavelength range (color) which is different in the source of continuation wide band light. This by making a light filter (for example, on a carousel) which is different at the suitable point of the lighting system of a level sensor, for example intervene selectively, By using some independently selectable light sources, it can attain using the light source which can adjust wavelength, or by using the beam portion chosen from rotation/oscillating prism in a small broadband beam. Next, the light of the wavelength from which a measurement beam differs is used using this level sensor, and measurement of some of wafer surfaces is performed on each point.

[0093]Another selection is being able to detect selectively the light of a wavelength range (color) which is different in a wideband detection machine, and replacing it. This, for example by arranging a light filter to the detecting optical system in front of a detector, It can attain by dividing a measurement beam into different wavelength spatially using prism, and detecting the beam of this different wavelength with a separate detector, or the method of others which analyze a broadband reflective beam by a spectrum in order to measure a wafer surface position.

[0094]It is also possible for combination approach to be used and for it to be made to carry out spectral resolution of both a projection system and the detection system by it naturally.

[0095]If there is no cross protection and the result which should come out of and carry out the result with each same measurement (as opposed to each wavelength), and is different by, therefore such measurement will be obtained, this shows existence of an effect which was touched in the paragraph of the upper beginning. Then, the improved wafer surface position measurement can be drawn using various techniques. For example, a consistent result may be amended or canceled. The technique of majority vote may also be used. Instead, based on the spectrometry of a wafer surface position, a actual position is derived and it is easy to be clear with the model which describes the spectral response of a resist and the wafer surface characteristic.

[0096]Since the described cross protection depends also on the incidence angle of the measurement beam on a wafer surface, it may want to evaluate this effect, and to also change this incidence angle so that it may subsequently be amended. Therefore, the further possible change to a level sensor is enabling it to perform it using a measurement beam by the incidence angle from which a wafer surface position differs.

Although one method of attaining this is the same spot on a wafer, it is forming the multiplex measurement beam which has a different incidence angle to separate projection and detecting optical system. Instead, an optical system is changeable so that the same projection and detection system may include a different optic axis related to various measurement beams. Another selection which makes the incidence angle changed in time is using rotation/advancing-side-by-side folded mirror (or other moving parts) for the optical system of a level sensor.

[0097] If there is no cross protection, the result with the same measurement by a different incidence angle should be come out of and made to be the same as that of the wavelength dependency explained above. Therefore, if there is inconsistency (change by an incidence angle), it avoids and compensates or a model can be made by the same method.

[0098] Of course, the above-mentioned additional feature and an improvement may be independently used for the photo sensor except having explained here together.

[0099]

[Work example 5] The 5th embodiment of this invention is shown in drawing 21. The 5th embodiment of this invention is extreme ultraviolet rays (EUV) of the wavelength of the range of 9 thru/or 16 nm, and a lithography device which uses reflexivity mask MA' as exposure radiation, for example. At least, functionally, although the parts of this 5th embodiment are generally the same as the thing of the 1st embodiment, it is made for them to suit the exposure radiation wavelength to be used, and those arrangement is adjusted so that it may be adapted for the beam course needed by use of a reflexivity mask. it is Lighting Sub-Division and projection optical system IL', and to optimize PL' on the wavelength of exposure radiation among special adaptation which may be necessity --; -- this is accompanied by generally using the optical element of the reflexivity instead of refractility. The example of illumination-light study system IL' used for an EUV radiation line is indicated to the European Patent application 00300784th and No. 6 (P-0129).

[0100] An important difference between a lithography device using a reflexivity mask and a thing using a penetrable mask is that the degree of complaint side of a mask becomes a position error on a wafer which increases according to a downstream optical system, i.e., light path length of projection lens PL', with a reflexivity mask. This is because height and/or slope deviation of a mask change locally an effective incidence angle of an illumination beam on a mask, therefore an XY position of an image form on a wafer is changed.

[0101] According to the 5th embodiment of this invention, influence of the degree of complaint side of a mask makes a height map of a mask in advance of exposure, and is avoided or reduced by controlling at least one mask position of Z, Rx, and Ry during exposure. Although this height map can be made by a method (namely, off-axis leveling of a mask in a measuring station) similar to having explained above,; however it may be made from a mask of an exposure station, and it may abolish the necessity of relating a height map with a physical reference surface. Although calculation of an optimal position of a mask under exposure or exposure scan (exposure course) may be equivalent to having explained above, it may combine it with optimization of a wafer and a mask exposure course. However, it may be more advantageous to put weight on the optimizing calculation, since slope deviation has big influence in a position in a wafer to a mask.

[0102] The lithography projection apparatus by this invention should also note clearly that two board tables (above) and/or two mask tables (above) may be included. In such a scenario, the 1st substrate on the 1st

board table receives height map creation in a measuring station, on the other hand, the 2nd substrate on the 2nd board table receives exposure simultaneously at an exposure station, and, in the case of; and two or more mask tables, same thing is possible. Such composition can enlarge a throughput dramatically.

[0103] This invention should note clearly that only substrate leveling is also applicable to combination of Masclet belling or substrate leveling, and Masclet belling.

[0104] Although a specific embodiment of this invention was described above, probably, it turns out that it may carry out with having explained this invention and an option. It does not mean that this explanation limits this invention.

[Brief Description of the Drawings]

[Drawing 1] The lithography projection apparatus by the 1st embodiment of this invention is shown.

[Drawing 2] It is a figure showing how to decide wafer height from measurement by the level sensor and Z interferometer.

[Drawing 3] It is a figure showing various processes of the off-axis leveling procedure by this invention.

[Drawing 4] It is a figure showing various processes of the off-axis leveling procedure by this invention.

[Drawing 5] It is a figure showing various processes of the off-axis leveling procedure by this invention.

[Drawing 6] It is a figure showing various processes of the off-axis leveling procedure by this invention.

[Drawing 7] It is a top view of the board table showing the sensor and standard which are used in the off-axis leveling procedure by this invention.

[Drawing 8] It is a side view of the exposure station of the 2nd embodiment of this invention, and a measuring station.

[Drawing 9] It is a flow chart showing various processes of the measurements process carried out at the measurement appearance station of the 2nd embodiment of this invention.

[Drawing 10] It is a flow chart showing various processes of the exposure process carried out at the exposure station of the 2nd embodiment of this invention.

[Drawing 11] It is a diagram showing the scanning pattern which can be used in order to measure the height map of this invention.

[Drawing 12] It is a diagram showing the alternative scanning pattern which can be used in order to measure the height map of this invention.

[Drawing 13] It is a global-area level outline process-line figure of the 2nd embodiment of this invention.

[Drawing 14] The structure of the embodiment of the level sensor which can be used for this invention suitable now is shown.

[Drawing 14 A] The projection lattice of the level sensor which can be used for this invention is shown in detail.

[Drawing 14 B] The mode of the level sensor which can be used for this invention of operation is shown.

[Drawing 14 C] The mode of the detection lattice of the level sensor which can be used for this invention of operation is shown.

[Drawing 14 D] The mode of the detection lattice of the level sensor which can be used for this invention of operation is shown.

[Drawing 14 E] The mode of the detection lattice of the level sensor which can be used for this invention of operation is shown.

[Drawing 14 F] The mode of the detector of the level sensor which can be used for this invention of operation is shown.

[Drawing 14 G] The output of the detector of the level sensor which can be used for this invention is shown.

[Drawing 15] It is a graph which shows the detector output versus board table position of the prehension spot of the level sensor of drawing 14.

[Drawing 15 A] It is a diagram showing the detector portion for a prehension spot of the level sensor of drawing 14.

[Drawing 16] It is a diagram showing the embodiment of the reliance sensor which can be used for the 2nd embodiment of this invention suitable now.

[Drawing 17] It is a diagram showing the embodiment of the reliance sensor which can be used for the 2nd embodiment of this invention suitable now.

[Drawing 18] It is a diagram of the beam splitter which can be used for drawing 16 and the reliance sensor of drawing 17.

[Drawing 19] It is a diagram used in order to explain Z interferometer calibration procedure which can be used for the embodiment of this invention.

[Drawing 20] It is a diagram showing the notation used when explaining the exposure route optimization procedure by the 3rd embodiment of this invention.

[Drawing 21] The lithography projection apparatus by the 5th embodiment of this invention is shown.

[Explanations of letters or numerals]

C Target portion

CO Capacitor

Ex Beam formed optical element

IF Position detecting means

IL' illumination-light study system

IN Integrator

LA Line source

MA Mask

MA' reflexivity mask

MT Mask table

PB projection beam

PL projection system

PL' projection system

W Substrate

WT board table

10 Level sensor

20a The 1st position detecting system

20b The 2nd position detecting system

111 Radiation source

113 Projection lattice

114 Projection optical system

121 Detecting optical system

126 Detection lattice

128 Detector

[Translation done.]

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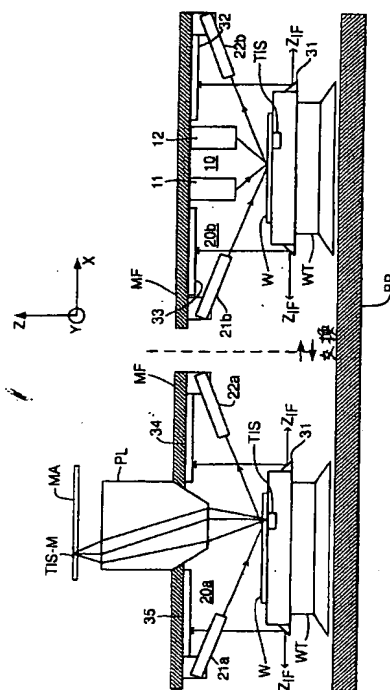
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(54) 【発明の名称】 リソグラフィック投影装置のオフアキシレベリング

(57) 【要約】

【課題】 複数の基板テーブルまたはマスクテーブルがあるリソグラフィ投影装置に於いて、複数のステーションでこの基板またはマスクの高さを測定する装置間の原点を関係付ける必要をなくすること。

【解決手段】 基板Wを基板テーブルWTに装填してから、測定ステーション (図8の右) で、レベルセンサ10を使って、物理的参照面の垂直位置および基板表面の垂直位置 Z_{LS} を複数の点で測定し、並びにZ干渉計ZIFを使ってこの基板テーブルの垂直位置 Z_{IF} を同じ点で同時に測定し、基板表面高さ、 $Z_{Wefer} = Z_{LS} + Z_{IF}$ をマップにする。次に、この基板を担持する基板テーブルを露出ステーション (図8の左) へ移し、物理的参照面の垂直位置を再び決定する。次に露出プロセス中に基板を正しい垂直位置に位置決めする際にこの高さマップを参照する。このプロセスは、マスクにも適用可能である。



【特許請求の範囲】

【請求項 1】 リソグラフィ投影装置であって：放射線の投影ビーム（P B）を供給するための放射線システム（L A、E x、I N、C O）；マスク（M A）を保持するためのマスクホルダを備える第 1 物体テーブル（M T）；基板（W）を保持するための基板ホルダを備える、第 2 の、可動物体テーブル（W T）；このマスクの被照射部分をこの基板の目標部分（C）上に結像するための投影システム（P L）；および上記第 2 物体テーブルを、上記投影システムが上記マスク部分を上記基板上に結像に出来る露出ステーションと測定ステーションの間で動かすための位置決めシステム；を含む投影装置に於いて；上記第 2 物体テーブルがそれに固定された物理的参照面を有し、さらに投影装置が、上記測定ステーションに位置し、上記基板ホルダ上に保持された基板（W）の表面上の複数の点の、上記物理的参照面に関する、高さを測定しおよびその高さマップを作るように構成および配設された高さマップ作成手段；上記露出ステーションに位置し、上記第 2 物体テーブルを上記露出ステーションへ動かしてから、上記物理的参照面の上記基板表面に実質的に垂直な第 1 方向に於ける位置を測定するための位置測定手段；並びに上記目標部分の露出中に、上記高さマップおよび上記位置測定手段によって測定した上記位置に従って、少なくとも上記第 1 方向に於ける上記第 2 物体テーブルの位置を制御するように構成および配設された制御手段；を有することを特徴とする装置。

【請求項 2】 請求項 1 による装置に於いて、上記制御手段が、更に、上記高さマップに従って上記第 2 物体テーブルの少なくとも上記第 1 方向に垂直な一つの軸の周りの傾きを制御するように設けられている装置。

【請求項 3】 請求項 1 または請求項 2 による装置に於いて、上記高さマップ作成手段が点の線形アレーの上記第 1 方向に於ける位置を測定するように構成および配設されたレベルセンサを含む装置。

【請求項 4】 請求項 1、請求項 2 または請求項 3 による装置に於いて、上記高さマップ作成手段が、上記第 1 方向に於ける位置を測定すべき表面によって反射された測定ビームの位置を測定するように構成および配設されたレベルセンサ（1 0）を含む装置。

【請求項 5】 請求項 4 による装置に於いて、上記レベルセンサ（1 0）が：投影格子（1 1 3）；上記投影格子の像を、上記第 1 方向に於ける位置を測定すべき表面上に投影するための投影光学系（1 1 4）；検出格子（1 2 6）、上記検出格子上に上記投影格子の像を作るために上記表面によって反射された光を集束するための検出光学系（1 2 1）；および上記投影格子の上記像が上記検出格子に重なることによって出来たモアレ図形を検出するための検出器（1 2 8）を含む装置。

【請求項 6】 請求項 5 による装置に於いて、上記レベルセンサが、更に、上記投影格子を多色放射線で照明するように構成および配設された放射線源（1 1 1）を含み、並びに上記投影光学系および上記検出光学系が本質的に反射性光学素子から成る装置。

【請求項 7】 請求項 1 ないし請求項 6 の何れか一つによる装置に於いて、上記高さマップ作成手段が、上記基板の表面上の第 1 方向に於ける位置を上記複数の点で検出するためのレベルセンサ（1 0）、上記レベルセンサによる測定と同時に上記第 2 物体テーブルの上記第 1 方向に於ける位置を検出するための位置検出手段（1 F）を含む装置。

【請求項 8】 請求項 7 による装置に於いて、上記位置検出手段が干渉計を含む装置。

【請求項 9】 請求項 1 ないし請求項 8 の何れか一つによる装置に於いて、上記位置測定手段が上記第 2 物体テーブルに取付けられたイメージセンサを含み、上記物理的参照面が上記イメージセンサの上面を含む装置。

【請求項 1 0】 請求項 1 ないし請求項 9 の何れか一つによる装置に於いて、上記位置測定手段が上記物理的参照面の、上記投影システムの焦点面に関する位置を測定するように構成および配設された装置。

【請求項 1 1】 請求項 1 ないし請求項 1 0 の何れか一つによる装置に於いて、上記第 2 物体テーブルが複数の離間した物理的参照面を有し、上記高さマップ作成手段が上記複数の点の、上記複数の物理的参照面によって形成される参照平面に関する高さを測定するように構成および配設された装置。

【請求項 1 2】 請求項 1 ないし請求項 1 1 の何れか一つによる装置であって、更に：上記露出ステーションに位置し、上記基板ホルダ上に保持された基板の表面上の上記複数の点の、上記物理的参照面に関する、高さを測定しおよびその高さマップを作るように構成および配設された第 2 高さマップ作成手段；および上記測定および露出ステーションに設けられた別々の位置検出システムのための相対校正を導き出すために、上記第 1 および第 2 高さマップ作成手段の各々によって用意された単一基板の高さマップを比較するように構成および配設された校正手段；を含む装置。

【請求項 1 3】 以下の構成を有するリソグラフィ投影装置を用いてデバイスを製造する方法であって：放射線の投影ビーム（P B）を供給するための放射線システム（L A、E x、I N、C O）；マスク（M A）を保持するためのマスクホルダを備える第 1 物体テーブル（M T）；基板（W）を保持するための基板ホルダを備える、第 2 の、可動物体テーブル（W T）；およびこのマスクの被照射部分をこの基板の目標部分（C）上に結像するための投影システム（P L）、上記第 1 物体テーブルにパターンを担持するマスク（M A）を設ける工程；上記第 2 物体テーブルに放射線感応

層を有する基板(W)を設ける工程；およびこのマスクの上記被照射部分をこの基板の上記目標部分上に結像する工程；を含む方法に於いて：上記結像工程の前で、測定ステーションにある該第2物体テーブルにより、この基板表面上の複数の点の、上記第2物体テーブル上の物理的参照面に関する、高さを示す高さマップを作る工程；この第2物体テーブルを上記露出ステーションへ動かし、上記物理的参照面の上記基板表面に実質的に垂直な第1方向に於ける位置を測定する工程；並びに上記結像工程中に、この第2物体テーブルを、上記高さマップおよび上記物理的参照面の上記第1方向に測定した上記位置を参照して、少なくとも上記第1方向に位置決めする工程；とを有することを特徴とする方法。

【請求項14】 請求項13による方法に於いて、上記結像工程中に、上記高さマップを参照することによって、上記第2物体テーブルを少なくとも上記第1方向に垂直な一つの軸の周りに方向付けする方法。

【請求項15】 請求項13または請求項14による方法に於いて、上記結像工程中に上記第2物体テーブルを、上記目標部分の領域に亘って積分した焦点ずれの自乗を最小にするように、配置し、この焦点ずれが上記投影レンズの焦平面と上記基板の表面との間の第1方向における距離である方法。

【請求項16】 請求項13または請求項14による方法に於いて、上記結像工程がスリット像を上記基板上に走査結像する工程を含み、および上記結像工程中に上記第2物体テーブルを、上記目標部分の領域に亘って積分した焦点ずれの自乗を最小にするように配置し、この焦点ずれが上記投影レンズの焦点面と上記基板の表面の間の上記第1方向に於ける距離を意味する方法。

【請求項17】 請求項13ないし請求項16の何れか一つによる方法に於いて、上記高さマップを作る工程が以下のサブ工程を含む方法：上記基板表面上の上記複数の点の各々の上記第1方向に於ける位置を測定する工程；上記基板表面上の点の位置の各測定と同時に、上記第2物体テーブルの上記第1方向における位置を測定する工程；および上記第2物体テーブルの測定位置の各々を上記高さマップを作るための上記基板表面の対応する測定位置から引く工程。

【請求項18】 請求項17による方法に於いて、上記高さマップを作る工程が上記物理的参照面の上記第1方向に於ける位置および同時に上記第2物体テーブルの上記第1方向に於ける位置を測定する初期工程を含む方法。

【請求項19】 請求項13ないし請求項18の何れか一つによる方法であって、更に、上記高さマップを作る工程の前に：露出すべき上記基板上の領域の周辺に近接する上記ウエハ表面上の複数の点の高さを測定する工程、並びに測定した高さから上記基板のための全体の高さおよび傾斜および／またはその高さをマップにすべき

上記基板表面のある領域の局部高さまたは傾斜値を決める工程を含む方法。

【請求項20】 請求項13ないし請求項19の何れか一つによる方法であって、更に、上記高さマップを作る工程の前に、上記高さマップを作る際に使用すべきレベルセンサ(10)を、上記レベルセンサを使って上記基板表面上の少なくとも一つの所定点の垂直位置の複数の測定を、この第2物体テーブルを上記複数の測定の異なるものに対して異なる垂直位置に配置して行うことによって、校正する工程を含む方法。

【請求項21】 請求項20による方法に於いて、上記校正工程を上記基板上の複数の異なる露出領域に対して行い、それぞれに得た校正補正値を、型式がこの校正を行ったものに対応する露出領域の高さマップを作る際に適用する方法。

【請求項22】 請求項13ないし請求項21の何れか一つの方法によって製造したデバイス。

【請求項23】 以下の構成を有するリソグラフィ投影装置を校正する方法であって：放射線の投影ビーム(PB)を供給するための放射線システム(LA、EX、IN、CO)；マスク(MA)を保持するためのマスクホルダを備える第1物体テーブル(MT)；基板(W)を保持するための基板ホルダを備える、第2の、可動物体テーブル(WT)；並びに上記第2物体テーブルのこのステーションでの位置を測定するための第1位置検出システム(20a)を有する測定ステーション；およびこのマスクの被照射部分をこの基板の目標部分(C)上に結像するための投影システム(PL)および上記第2物体テーブルのこのステーションでの位置を測定するための第2位置検出システム(20b)を有する露出ステーション；上記第2物体テーブルに基板(W)を設ける工程；上記測定ステーションで、上記基板表面上の複数の点の、上記基板の表面に実質的に垂直な第1方向に於ける位置および同時に上記第2物体テーブルの位置を上記第1位置検出システムを使って測定することによって上記基板の第1高さマップを作る工程；上記露出ステーションで、上記基板表面上の上記複数の点の上記第1方向に於ける位置および同時に上記第2物体テーブルの位置を上記第2位置検出システムを使って測定することによって上記基板の第2高さマップを作る工程；並びに上記第1および第2位置検出システムを校正するために上記第1および第2高さマップを比較する工程；を含む方法。

【請求項24】 以下の構成を有するリソグラフィ投影装置を用いてデバイスを製造する方法であって：マスク(MA)を保持するためのマスクホルダを備える第1物体テーブル(MT)；基板(W)を保持するための基板ホルダを備える、第2の、可動物体テーブル(WT)；およびこのマスクの被照射部分をこの基板の目標部分(C)上に結像するための投影システム(PL)；上記

第1物体テーブルにパターンを担持するマスク(MA)を設ける工程；上記第2物体テーブルに放射線感応層を有する基板(W)を設ける工程；およびこのマスクの上記被照射部分をこの基板の上記目標部分上に結像する工程；を含み、

複数の基板を露出するために、上記基板を設ける工程および結像する工程を繰返す方法に於いて：この第2物体テーブルに設けた各基板に対して、この基板表面上の複数の点の高さを示す高さマップを作る工程；および上記第2物体テーブルの汚染または機構的欠陥を示すかも知れない不平面度の位置の相関を検出するために逐次得られた基板の高さマップを比較する工程；を有することを特徴とする方法

【請求項25】 リソグラフィ投影装置であって、放射線の投影ビーム(PB)を供給するための放射線システム(LA、IL')；反射性マスク(MA')を保持するためのマスクホルダを備える第1の、可動物体テーブル(MT)；基板(W)を保持するための基板ホルダを備える、第2の、物体テーブル(WT)；およびこのマスクの被照射部分をこの基板の目標部分(C)上に結像するための投影システム(PL')；を含む投影装置であって：上記マスクホルダ上に保持された反射性マスクの平面上の複数の点の、参照面に関する、高さを測定しおよびその高さマップを作るように構成および配設された高さマップ作成手段；並びに上記目標部分の露出中に、上記高さマップに従って、上記第1物体テーブルの少なくとも上記第1方向に於ける位置を制御するように構成および配設された制御手段；を有することを特徴とする装置。

【請求項26】 以下の構成を有するリソグラフィ投影装置を用いてデバイスを製造する方法であって：放射線の投影ビーム(PB)を供給するための放射線システム(LA、IL')；反射性マスク(MA')を保持するためのマスクホルダを備える第1の、可動物体テーブル(MT)；基板(W)を保持するための基板ホルダを備える第2物体テーブル(WT)；およびこのマスクの被照射部分をこの基板の目標部分(C)上に結像するための投影システム(PL')；上記第1物体テーブルにパターンを担持する反射性マスク(MA')を設ける工程；上記第2物体テーブルに放射線感応層を有する基板(W)を設ける工程；およびこのマスクの上記被照射部分をこの基板の上記目標部分上に結像する工程を含む方法に於いて：上記結像工程の前の、このマスク表面上の複数の点の、上記第1物体テーブル上の参照平面に関する、高さを示す高さマップを作る工程；および上記結像工程中に、この第1物体テーブルを、上記高さマップを参照して、少なくとも上記第1方向に位置決めする工程；に特徴がある方法。

【発明の詳細な説明】

【0001】

【発明の属する技術分野】本発明は、リソグラフィ装置に於ける、例えば、基板および／またはマスクの、高さ検出およびレベリングに関する。更に詳しくは、この発明は、リソグラフィ投影装置であって：放射線の投影ビームを供給するための放射線システム；マスクを保持するためのマスクホルダを備える第1物体テーブル；基板を保持するための基板ホルダを備える、第2の、可動物体テーブル；このマスクの被照射部分をこの基板の目標部分上に結像するための投影システム；および上記第2物体テーブルを、上記投影システムが上記マスク部分を上記基板上に結像に出来る露出位置と測定位置の間で動かすための位置決めシステム；を含む投影装置に於けるオフアクシスレベリング用システムに関する。

【0002】

【従来の技術】簡単のために、この投影システムを、以後“レンズ”と呼ぶかも知れないが；この用語は、例えば、屈折性光学素子、反射性光学素子、反射屈折性光学素子、および荷電粒子光学素子を含む、種々の型式の投影システムを包含するように広く解釈すべきである。この放射線システムもこれらの原理の何れかに従って放射線の投影ビームを指向し、成形または制御するために作用する素子を含んでもよく、そのような素子も以下で集成的または単独に“レンズ”と呼んでもよい。その上、この第1および第2物体テーブルを、それぞれ、“マスクテーブル”および“基板テーブル”と呼んでもよい。更に、このリソグラフィ装置は、二つ以上のマスクテーブルおよび／または二つ以上の基板テーブルを有する型式のものでもよい。そのような“多段”装置では、追加のテーブルを並列に使ってもよく、または準備工程を一つ以上のテーブルで実施し、一方、一つ以上の他のテーブルを露出用に使ってもよい。

【0003】リソグラフィ投影装置は、例えば、集積回路(IC)の製造に使うことができる。そのような場合、マスク(レチクル)がこのICの個々の層に対応する回路パターンを含んでもよく、このパターンを、感光材料(レジスト)の層で塗被した基板(シリコンウエハ)の露出領域(ダイ)上に結像することができる。一般的に、1枚のウエハが隣接するダイの全ネットワークを含み、それらをレチクルを経て、一度に一つずつ、順次照射する。リソグラフィ投影装置の一つの型式では、全レチクルパターンをダイ上に一度に露出することによって各ダイを照射し；そのような装置を普通ウエハステップと呼ぶ。普通ステップ・アンド・スキャン装置と呼ぶ代替装置では、このレチクルパターンを投影ビームで与えられた基準方向(“走査”方向)に順次走査し、一方、一般的に、この投影システムが倍率M(一般的に<1)とし、ウエハテーブルを走査する速度vとすると、倍率M掛ける速度であるレチクルテーブルを走査する速度で、ウエハテーブルをこの方向に平行または逆平行に同期して走査することによって各ダイを照射する。こ

に説明したようなリソグラフィ装置に関する更なる情報は、例えば、国際特許出願WO97/33205から収集することができる。

【0004】極最近まで、リソグラフィ装置は、単一マスクテーブルおよび単一基板テーブルを含んだ。しかし、今や少なくとも二つの独立に可動の基板テーブルがある機械が利用可能である；例えば、国際特許出願WO98/28665およびWO98/40791に記載されている多段装置を参照されたい。そのような多段装置の背後の基本動作原理は、第1基板テーブルがその上にある第1基板を露出するために投影システムの下にある間に、第2基板テーブルが装填位置へ移動でき、露出した基板を排出し、新しい基板を取上げ、この新しい基板に幾つかの初期測定を行い、および次に第1基板の露出が完了するとすぐ、この新しい基板を投影システムの下10の露出位置へ移送するために待機し；そこでこのサイクルを繰返すことである。この様にして、機械のスループットをかなり向上することが可能であり、結果としてこの機械の所有コストを改善する。この同じ原理を、露出位置と測定位置の間を動く一つだけの基板テーブルに使用することを理解すべきである。

【0005】この測定位置で基板に行う測定は、例えば、基板（“ダイ”）上の種々の意図する露出領域、基板上の参照マーカ、および基板テーブル上の基板領域の外側に位置する少なくとも一つの参照マーカ（例えば、基準の）の間の空間関係（XおよびY方向の）の決定を含んでもよい。そのような情報は、後に投影システムに関する露出領域の迅速にして正確なXおよびY位置決めを行うために露出位置で使用することが出来；更なる情報については、例えば、WO99/32940（P-0079）参照。この明細書では、種々の点での、基板表面のZ位置を基板ホルダの参照面に対して、関連させ高さマップの測定点での準備も記載する。しかし、この参照面は、測定位置でZ干渉計によって定め、露出位置では、別のZ干渉計を使用する。従って、二つのZ干渉計の原点の間の正確な関係を知ることが必要である。

【0006】

【発明が解決しようとする課題】本発明の目的は、リソグラフィ投影装置に於いて、二つの干渉計システムの原点を関係付ける必要を回避し、且つ露出プロセス中に露出領域の位置決めの付加的改善を可能にする、基板のオフアクシスレベリングをするためのシステムを提供することである。

【0007】

【課題を解決するための手段】本発明によれば、リソグラフィ投影装置であって：放射線の投影ビームを供給するための放射線システム；マスクを保持するためのマスクホルダを備える第1物体テーブル；基板を保持するための基板ホルダを備える、第2の、可動物体テーブル；このマスクの被照射部分をこの基板の目標部分上に結像

するための投影システム；および上記第2物体テーブルを、上記投影システムが上記マスク部分を上記基板上に結像に出来る露出ステーションと測定ステーションの間で動かすための位置決めシステム；を含む投影装置に於いて；上記第2物体テーブルがそれに固定された物理的参照面を有し、並びに：投影装置は、上記測定ステーションに位置し、上記基板ホルダ上に保持された基板の表面上の複数の点の、上記物理的参照面に関する、高さを測定しおよびその高さマップを作るように構成および配設された高さマップ作成手段；上記露出ステーションに位置し、上記第2物体テーブルを上記露出ステーションへ動かしてから、上記物理的参照面の上記基板表面に実質的に垂直な第1方向に於ける位置を測定するための位置測定手段；並びに上記目標部分の露出中に、上記高さマップおよび上記位置測定手段によって測定した上記位置に従って、少なくとも上記第1方向に於ける上記第2物体テーブルの位置を制御するように構成および配設された制御手段と；を有することを特徴とする装置が提供される。

【0008】本発明の更なる態様によれば、放射線の投影ビームを供給するための放射線システム；マスクを保持するためのマスクホルダを備える第1物体テーブル；基板を保持するための基板ホルダを備える、第2の、可動物体テーブル；およびこのマスクの被照射部分を露出ステーションでこの基板の目標部分上に結像するための投影システムとを含むリソグラフィ投影装置を使うデバイスの製造方法であって：上記第1物体テーブルにパターンを担持するマスクを設ける工程；上記第2物体テーブルに放射線感応層を有する基板を設ける工程；およびこのマスクの上記被照射部分をこの基板の上記目標部分上に結像する工程を含む方法に於いて：上記結像工程の前の、この第2物体テーブルが測定ステーションにあって、この基板表面上の複数の点の、上記第2物体テーブル上の物理的参照面に関する、高さを示す高さマップを作る工程；この第2物体テーブルを上記露出ステーションへ動かし、上記物理的参照面の上記基板表面に実質的に垂直な第1方向に於ける位置を測定する工程；並びに上記結像工程中に、この第2物体テーブルを、上記高さマップおよび上記物理的参照面の上記第1方向に測定した上記位置を参照して、少なくとも上記第1方向に位置決めする工程に特徴がある方法が提供される。

【0009】

【発明の実施の形態】この発明によるリソグラフィ投影装置を使う製造プロセスでは、マスクのパターンを、少なくとも部分的にエネルギー感応性材料（レジスト）で覆われた基板上に結像する。この結像工程の前に、この基板は、例えば、下塗り、レジスト塗布およびソフトベークのような、種々の処理を受けるかも知れない。露出後、基板は、例えば、露出後ベーク（PEB）、現像、ハードベークおよび結像形態の測定／検査のような、他

の処理を受けるかも知れない。この一連の処理は、デバイス、例えば IC の個々の層をパターン化するための基礎として使用する。そのようにパターン化した層は、次に、エッチング、イオン注入（ドーピング）、金属化処理、酸化処理、化学・機械的研磨等のような、全て個々の層の仕上げを意図した種々の処理を受けるかも知れない。もし、幾つかの層が必要ならば、全処理またはその変形を各新しい層に反復しなければならないだろう。結局、デバイスのアレー（ダイ）が基板（ウエハ）上にできる。次に、これらのデバイスをダイシングまたは鋸引

のような手法によって互いから分離し、そこから個々のデバイスをキャリアに取付け、ピンを接続するようにできる。そのようなプロセスに関する更なる情報は、例えば、ピータ・バン・ザントの“マイクロチップの製作：半導体加工の実用ガイド”、第 3 版、マグロウヒル出版社、1997 年、ISBN0-07-067250-4 などの書物から得ることができる。

【0010】本文では、この発明による装置を IC の製造に用いるべく特に説明をしてもよいが、そのような装置に多くの他の用途の可能性があると明確に理解すべきである。例えば、それを集積光学系、磁区メモリ用誘導検出パターン、液晶ディスプレイパネル、薄膜磁気ヘッド等の製造に使ってもよい。当業者は、そのような代替用途の関係では、この本文で使う“レチクル”、“ウエハ”または“ダイ”という用語のどれも、それぞれ、より一般的な用語“マスク”、“基板”および“露出領域”で置換えられると考えるべきであることが分るだろう。

【0011】本明細書では、“放射線”および“ビーム”という用語を使って、紫外線（例えば、365 nm、248 nm、193 nm、157 nm または 126 nm の波部）、極紫外線（EUV）、X 線、電子およびイオンを含むが、それに限定されないあらゆる種類の電磁波放射または粒子束を包含する。やはりここでは、この発明を直交 X、Y および Z 方向の参照系を使って説明し、I 方向に平行な軸周りの回転を R1 で表す。更に、文脈が別のことを要求するのでなければ、ここで使う“垂直”（Z）という用語は、この装置の何れか特定の方向を意味するのではなく、基板またはマスク面に垂直な方向を指す。

【0012】

【実施例 1】以下に実施例および添付の概略図を参照して本発明を説明する。図 1 は、この発明によるリソグラフィ投影装置を概略的に示す。この装置は：

● 放射線（例えば、UV または EUV）の投影ビーム PB を供給するための放射線システム LA、Ex、IN、CO；

● マスク MA（例えば、レチクル）を保持するためのマスクホルダを備え、このマスクを部材 PL に関して正確に位置決めするための第 1 位置決め手段に結合された

第 1 物体テーブル（マスクテーブル）MT；

● 基板 W（例えば、レジストを塗被したシリコンウエハ）を保持するための基板ホルダを備え、この基板を部材 PL に関して正確に位置決めするための第 2 位置決め手段に結合された第 2 物体テーブル（基板またはウエハテーブル）WTa；

● 基板 W（例えば、レジストを塗被したシリコンウエハ）を保持するための基板ホルダを備え、この基板を部材 PL に関して正確に位置決めするための第 3 位置決め手段に結合された第 3 物体テーブル（基板またはウエハテーブル）WTb；

● 測定ステーションで基板テーブル WTa または WTB 上に保持された基板上に測定（特性表示）プロセスを行うための測定システム MS；および

● 露出ステーションで基板テーブル WTa または WTB に保持された基板 W の露出領域 C（ダイ）上にこのマスク MA の被照射部分を結像するための投影システム（“レンズ”）PL（例えば、屈折若しくは反射屈折性のシステム、ミラーグループまたは視界偏向器アレー）を含む。

【0013】ここに示すように、この装置は、透過型である（即ち、透過型マスクを有する）。しかし、一般的に、それは、例えば、反射型でもよい。

【0014】この放射線システムは、放射線のビームを作る線源 LA（例えば、水銀ランプ、エグザミナレーザ、貯蔵リングまたはシンクロトロン）の電子ビームの経路の周りに設けたアンジュレータ、レーザプラズマ源、または電子若しくはイオンビーム源を含む。このビームを、この照明システムに含まれる種々の光学部品、一例えば、ビーム成形光学素子 Ex、インテグレート IN およびコンデンサ CO に通して出来たビーム PB が所望の形状およびその断面での強度分布を有するようにする。

【0015】このビーム PB は、続いてマスクテーブル MT 上のマスクホルダに保持されているマスク MA を横切る。マスク MA を通過してから、ビーム PB は、レンズ PL を通過し、そのレンズがビーム PB を基板 W の露出領域 C 上に集束する。干渉計変位および測定手段 IF を使って、基板テーブル WTa、WTb を第 2 および第 3 位置決め手段によって正確に動かすことができ、例えば、異なる露出領域 C をビーム PB の経路内に配置する。同様に、第 1 位置決め手段を使って、例えば、マスク MA をマスクライブラリーから機械的に取出してから、このマスク MA をビーム PB の経路に関して正確に配置することができる。一般的に、物体テーブル MT、WTa、WTb の移動は、図 1 にはっきりは示さないが、長ストロークモジュール（粗位置決め）および短ストロークモジュール（微細位置決め）を使って実現する。ウエハステップパの場合は（ステップ・アンド・スキャン装置と違って）、レチクルテーブルを短ストローク

位置決め装置にだけ結合して、マスクの向きおよび位置の微細調整を行ってもよい。

【0016】この第2および第3位置決め手段は、それぞれそれぞれの基板テーブルWTa、WTbを投影システムPLの下に露出ステーションおよび測定システムMSの下に測定ステーションの両方を含む範囲に亘って位置決めできるように構成してもよい。その代りに、この第2および第3位置決め手段を、基板テーブルをそれぞれの露出ステーションに位置決めするための別々の露出ステーションおよび測定ステーション位置決めシステム並びにこれらの基板テーブルを二つの位置決めシステムの間で交換するためのテーブル交換手段で置換えてもよい。適当な位置決めシステムは、とりわけ上記のWO98/28665およびWO98/40791に記載されている。リソグラフィ装置は、多段露出ステーションおよび/または多段測定ステーションを有してもよいこと、並びに測定ステーションの数と露出ステーションの数が互いに異なってもよく、ステーションの全数が基板テーブルの数と等しい必要がないことに注意すべきである。実際、露出および測定ステーションを別々とする原理は、単一基板テーブルにおいても通用する。

【0017】図示する装置は、二つの異なるモードで使うことができる：1. ステップ・アンド・リピート（ステップ）モードでは、マスクテーブルMTを本質的に固定して保持し、全マスク画像を露出領域C上に一度に（即ち、単一“フラッシュ”で）投影する。次に、基板テーブルMTをXまたはY方向に移動して異なる露出領域CをビームPBによって照射できるようにし；2. ステップ・アンド・スキャン（走査）モードでは、与えられた露出領域Cを単一“フラッシュ”で露出しないことを除いて、本質的に同じシナリオを適用する。その代りに、マスクテーブルMTが与えられた方向（所謂“走査”方向、例えば、Y方向）に速度vで動き得て、投影ビームPBにマスク画像上を走査させ；それと共に、基板テーブルWTaまたはWTbを同じまたは反対方向に $V=Mv$ の速度で同時に動かす。但し、MはレンズPLの倍率（典型的には、 $M=1/4$ または $1/5$ ）である。この様にして、比較的大きな露出領域Cを、解像度で妥協する必要なく、露出することが出来る。

【0018】リソグラフィ装置の結像品質に影響する重要な要因は、マスク画像を基板上に集束する精度である。実際には、投影システムPLの焦点面の位置を調整するための範囲に限られ、そのシステムの焦点深度が浅いので、これは、ウエハ（基板）の露出領域を投影システムPLの焦点面に正確に配置しなければならないことを意味する。これをするためには、勿論、投影システムPLの焦点面の位置とウエハの上面の位置の両方を知る必要がある。ウエハは、超高平面度に研磨するが、それにも拘らず、焦点精度に顕著に影響するに十分な大きさ

の、ウエハ表面の完全平面度からの逸脱（“不平面度”と称する）が起り得る。不平面度は、例えば、ウエハ厚さのばらつき、ウエハ形状の歪みまたはウエハホルダの汚れによって生ずるかも知れない。先の処理工程による構造物の存在もウエハの高さ（平面度）にかなり影響する。本発明では、不平面度の原因が大部分無関係で；ウエハの上面の高さだけを考える。特記しない場合には、以下に称する“ウエハ表面”は、その上にマスク画像を投影する、ウエハの上面を指す。

【0019】この発明によれば、ウエハを基板テーブルに装填してから、この基板テーブルの物理的参照面に対するウエハ表面の高さ Z_{Wefer} をマップにする。このプロセスは、測定ステーションで、レベルセンサと称する第1センサを使ってこの物理的参照面の垂直（Z）位置およびウエハ表面の垂直位置 Z_{LS} を複数の点で測定し、並びに第2センサ、例えばZ干涉計、を使ってこの基板テーブルの垂直位置、 Z_{IF} を同じ点で同時に測定することによって行う。図2に示すように、ウエハ表面高さは、 $Z_{\text{Wefer}} = Z_{\text{LS}} - Z_{\text{IF}}$ として決定する。次に、このウエハを担持する基板テーブルを露出ステーションへ移し、物理的参照面の垂直位置を再び決定する。次に露出プロセス中にウエハを正しい垂直位置に位置決めする際にこの高さマップを参照する。この手順を以下に図3ないし図6を参照して更に詳しく説明する。

【0020】図3に示すように、最初に基板テーブルを、この基板テーブルに固定した物理的参照面がレベルセンサLSの下にあるように動かす。この物理的参照面は、基板テーブル上のX、YおよびZ位置がこのリソグラフィ装置でのウエハの処理中に、および最も重要なことには、基板テーブルを測定ステーションと露出ステーション間での移動の際に、変らなければ何か都合のよい面でよい。この物理的参照面は、他の整列マークを含む基準の一部でもよく、且つウエハ表面の垂直位置を測定するのと同じセンサでその垂直位置を測定させるような性質を有すべきである。現在好適な実施例で、この物理的参照面は、中に所謂透過型イメージセンサ（TIS）を挿入する基準の反射面である。以下に、このTISを更に説明する。

【0021】このレベルセンサは、例えば、米国特許第5,191,200号（P-0039）（その中で焦点誤差検出システムと称する）に記載されているような光センサでもよく；その代りに空気圧または容量センサ（例えば）が考えられる。ウエハ面によって反射した投影格子の像と固定検出格子の間に作ったモアレ図形を使うセンサの現在好適な形を、以下にこの発明の第2実施例に関連して説明する。このレベルセンサは、複数の位置の垂直位置を同時に測定してもよく、および各々に対し小さい面積の平均高さを測定して、高さ空間周波数の不平面度を平均してもよい。

【0022】レベルセンサLSによる物理的参照面の垂

直位置の測定と同時に、Z 干渉計を使って基板テーブルの垂直位置、 Z_{IF} を測定する。この Z 干渉計は、例えば、WO99/28790 (P-0077) または WO99/32940 (P-0079) に記載されているような、3、5 または 6 軸干渉計式計測システムの一部でもよい。この Z 干渉計システムは、基板テーブルの垂直位置を XY 平面でレベルセンサ L S の較正した測定位置と同じ位置を有する点で測定するのが好ましい。これは、基板テーブル W T の二つの対向する側の垂直位置を、このレベルセンサの測定位置と一致する点で測定し、それらの間を補間／モデリングすることによって行ってもよい。これは、ウエハテーブルが XY 平面から傾斜する場合、この Z 干渉計測定がレベルセンサの下

の基板テーブルの垂直位置を正しく示すことを保証する。
【0023】このプロセスを、この第 1 物理的参照面から、例えば、対角線的に離間した、少なくとも第 2 物理的参照面で繰返すのが好ましい。すると、二つ以上の位置からの高さ測定を使って参照面を定めることが出来る。

【0024】一つ以上の物理的参照面の垂直位置と基板テーブルの垂直位置の同時測定は、ウエハ高さをマップにすべき基準となる参照平面を決める点を確認する。上記の種類の Z 干渉計は、絶対センサよりも事実上変位センサであり、それでゼロ合せが必要であるが、広範囲に亘って高度に線形的位置測定を提供する。他方、適当なレベルセンサ、例えば、上記のものは、外部に決めた参照平面（即ち、称呼ゼロ）に関して絶対位置測定を提供するが、小さい範囲に亘ってである。そのようなセンサを使う場合、物理的参照面がレベルセンサの測定範囲の中間で称呼ゼロに位置するまで基板テーブルを垂直に動か

かし、現在の干渉計 Z 値を讀出すのが好都合である。物理的参照面についての一つ以上のこれらの測定が高さマップ作成のための参照平面を確立するだろう。次に、この参照平面に関して Z 干渉計をゼロに合わせる。この様にして、この参照平面を基板テーブル上の物理的面に関係付け、 Z_{Wefer} 高さマップを、測定ステーションでの Z 干渉計の初期ゼロ位置および基板テーブルを動かすベースプレートの不平面度のような他の局部因子と無関係に作る。その上、この高さマップをレベルセンサのゼロ位置のドリフトと無関係に作る。
【0025】図 4 に示すように、一旦この参照平面を確立すると、高さマップを作るためにウエハ面がレベルセンサの下で走査されるように基板テーブルを動かす。ウエハ面の垂直位置および基板テーブルの垂直位置を既知の XY 位置の複数の点で測定し、互いから引いて既知の XY 位置でのウエハ高さを得る。これらのウエハ高さ値がウエハ高さマップを形成し、それを適当な形で記録することが出来る。例えば、これらのウエハ高さ値および XY 座標を一緒に所謂目に見えない対に記憶してもよ

い。その代りに、ウエハ高さ値を採る点を、例えば、ウエハを所定の経路に沿って所定の速度で走査し、所定の間隔で測定することによって、予め決めて、単純なリストまたは高さ値のアレー（任意に測定パターンおよび／または開始点を定める少数のパラメータと共に）がこの高さマップを決めるに十分であるようにする。

【0026】高さマップ作成走査中の基板テーブルの運動は、大部分 XY 平面内だけである。しかし、もし、レベルセンサ L S が確実なゼロ読みだけを提供する型式であれば、ウエハ面をこのレベルセンサのゼロ位置に保つために、基板テーブルを垂直にも動かす。そこでウエハ高さを、レベルセンサからのゼロ読みを維持するために必要な、Z 干渉計によって測定した、基板テーブルの Z 運動から本質的に誘導する。しかし、出力がウエハ高さ

と線形に関係する、または線形化できる測定範囲がかなり広いレベルセンサを使うのが好ましい。そのような測定範囲は、理想的には、ウエハ高さの最大予測、または許容ばらつきを包含する。そのようなセンサによれば、走査速度がウエハの輪郭を 3 次元で追跡するための短ストローク基板テーブルの能力によってではなく、センサの応答時間によって制限されるので、この操作中の基板テーブルの垂直運動の必要は減るか、無くなり、走査を速く終えることが出来る。また、直線範囲の広いセンサは、複数の位置（例えば、点のアレー）で高さを同時に測定できるようにする。

【0027】次に、ウエハテーブルを露出ステーションへ動かし、図 5 に示すように、この（物理的）参照面を投影レンズの下に配置して、この投影レンズの焦点面に対するその垂直位置の測定が出来るようにする。好適実施例で、これは、その検出器を前の測定で使用した参照面に物理的に結合した、一つ以上の透過型イメージセンサ（以下に説明する）を使って達成する。この透過型イメージセンサは、投影レンズの下

のマスクから投影した像の垂直合焦位置を決めることが出来る。この測定を用意して、この参照平面を投影レンズの焦点面に関係付けることが出来、およびウエハ面を最適焦点に保つ、3 次元での基板テーブルのための経路を決めることが出来る。これを行える一つの方法は、この走査経路に沿う一連の点に対する Z、 R_x および R_y 設定点を計算することである。これらの設定点は、ウエハマップデータと露出スリット像の焦点面の間の差を最小にするように最小自乗法を使って決める。計算を容易にするために、露出スリット像とウエハの相対運動をスリットが静的ウエハに対して動くとして表現することが出来る。すると、この最小自乗基準は、各時間 t に対し、次の式の最小値を与える $Z(t)$ 、 $R_x(t)$ および $R_y(t)$ の値を見付けることとして表すことができる：

【0028】

【数 1】

$$LSQ(t) = \frac{1}{s} \cdot \frac{1}{W} \int_{-\frac{s}{2}}^{\frac{s}{2}} \int_{-\frac{W}{2}}^{\frac{W}{2}} [w(x,y) \cdot (Z(t) + x \cdot R_x(t) + y \cdot R_y(t))]^2 dx dy \quad [1]$$

但し、 $w(x, y)$ はウエハ高さマップであり、露出スリットは、走査方向の幅 s およびこの走査方向に垂直な長さ W の矩形平面であり、その位置は $Z(t)$ 、 $R_x(t)$ および $R_y(t)$ によって定められる。これらの設定点およびウエハ経路は、 Y (走査方向の位置) または t (時間) の関数として表すことが出来、それはこれら $Y = y_0 + v t$ によって関係付けられているからである。但し y_0 は開始点であり、 v は走査速度である。

【0029】上記のように、物理的参照面は、中に透過型イメージセンサ (TIS) を挿入する面が好ましい。図 7 に示すように、二つのセンサ TIS1 および TIS2 を、基板テーブル (WT, WT a、または WT b) の上面に取付けた基準プレートに、ウエハ W が覆う領域の外側に対角線的に対向する位置で取付ける。この基準プレートは、非常に低熱膨張係数で高度に安定した材料、例えばアンバーで作り、平坦な反射上面を有し、それが整列プロセスで使うマークを平坦に保持してもよい。TIS1 および TIS2 は、投影レンズの空中像の垂直 (および水平) 位置を直接測定するために使うセンサである。それらは、それぞれの表面に開口を含み、その近くの後ろに露出プロセス用に使う放射線に感応する光検出器が配置されている。焦点面の位置を決めるために、投影レンズが、マスク MA 上に設け且つ明・暗コントラスト領域を有する TIS のパターン TIS-M の像を空間に投影する。次に、基板ステージを水平 (1 方向または好ましくは 2 方向に) および垂直に走査し、TIS の開口がこの空中像があると予測される空間を通過するようにする。TIS 開口が TIS パターンの像の明・暗部を通過すると、光検出器の出力が変動するだろう。光検出器出力の振幅な変化速度が最大である垂直レベルは、TIS パターンの像が最大のコントラストを有するレベルを示し、従って最適焦点の平面を示す。この種の TIS の例は、米国特許第 4,540,277 号に非常に詳細に記載されている。TIS の代りに、米国特許第 5,144,363 号に記載されているような反射イメージセンサ (RIS) も使ってよい。

【0030】物理的参照面として TIS の表面を使うことは、TIS 測定が高さマップのために使う参照平面を投影レンズの焦点面に直接関係付けるという利点を有し、それで高さマップを露出プロセス中にウエハステージのために高さ補正を与えるために直接使用することが出来る。これを図 6 に図解し、それは、ウエハ表面が投影レンズ PL の下の正しい位置にあるように、高さマップによって決められた高さで Z 干渉計の制御の下で位置付けられた基板テーブル WT を示す。

【0031】この TIS 表面は、付加的に参照マーカを

平坦に保持し、その位置を TTL (レンズを通す) 整列システムを使って検出して基板テーブルをマスクに整列してもよい。そのような整列システムは、例えば、EP-O, 467, 445 A (P-0032) に記載されている。個々の露出領域の整列も、露出領域をウエハステージ上の参照マーカに整列するために測定ステージで行う整列手続によって行うことが出来るか、またはそれによって不要にされてもよい。そのような手続は、例えば、EP-O906590 A (P-0070) に記載されている。

【0032】生産プロセスで、ステップ・アンド・リピートおよびステップ・アンド・スキャンの両モードで投影システム PL によって投影するマスク画像は、単一点ではなく、XY 平面でかなりの領域に亘って拡がること分るだろう。ウエハ高さがこの領域に亘ってかなりばらつくかも知れないので、焦点合せを単一点だけでなく、この投影領域全体に亘り最適化することが望ましい。本発明の実施例では、これを、基板テーブル WT の垂直位置だけでなく、その X および Y 軸周りの傾き (R_x , R_y) も制御することによって達成できる。意図する露出領域の位置および範囲を知り、本発明によって作った高さマップを使って、各露出に対する基板テーブルの最適 Z、 R_x および R_y 設定点を予め計算できる。これは、ウエハが投影レンズの下に位置するときウエハ高さだけを測定する既知の装置でレベリングするために必要な時間を省略し、従ってスループットを増大する。最適 Z、 R_x および R_y 設定点は、既知の種々の数学的手法を使って、例えば、対話型プロセスを使い、露出領域全体に亘って積分した焦点ずれ (ウエハ表面と理想的焦点面の間の距離として定義する)、すなわち $LSQ(t)$ を最小にすることによって計算してもよい。

【0033】更なる利点がステップ・アンド・スキャン・モードで可能である。このモードでは、投影レンズがマスクパターンの一部だけの像を露出領域の対応する部分上に投影する。次に、このマスクおよび基板を投影システム PL の物体および像焦点面の端から端まで同期して走査し、全マスクパターンを全露出領域上に結像する。実際には、投影レンズを固定し、マスクおよび基板を動かすが、このプロセスをウエハ表面上を動く像スリットに置換えて考えることが屡々便利である。本発明によって予め決めた高さマップで、XY 走査経路 (通常、走査は一方向、例えば、Y にだけ行う) に整合する一連の Z、 R_x および R_y 設定点を計算することが可能である。この一連の設定点は、追加の基準によって、例えば、スループットを増し、または望ましくない振動を誘起するかも知れない垂直加速度または傾斜運動を最小に

することによって最適化できる。離間した一連の設定点を与えられたとすると、多項式またはスプライン適合手順を使って露出に対する走査経路を計算できる。

【0034】本発明は、与えられた露出に対してウエハをZ、RxおよびRyで最適位置に配置することを意図するものであるが、露出領域全体に亘りウエハ高さが変動するので、ウエハを全領域にわたり十分に焦点合せするように配置出来ないかも知れない。そのような所謂焦点スポットは、露出不良を生ずることがある。しかし、本発明でそのような不具合を予め予測することが出来、修復作業を行うことが出来る。例えば、ウエハを剥がし、露出不良のウエハを更なる処理に悪影響することなく塗直すことが出来る。その代りに、もし、予測した不良がこのウエハ上の一つまたは僅かなデバイスにしか影響せず、他は合格であるならば、予め不良デバイスが出来ると予測できる露出を飛ばすことによってスループットを向上してもよい。

【0035】焦点スポット検出の更なる利点は、作った高さマップの解析から得ることが出来る。ウエハ高さマップに大域的ウエハ面からの大変位が存在するとき、これは、基板不平面度またはプロセス影響による焦点汚れを示すことがある。幾つかのウエハからのウエハ高さマップの比較は、基板テーブルの汚染または不平面度による焦点汚れを示すことが出来る。焦点汚れが異なるウエハに対して同じまたはほぼ同じ位置に現れるとき、これは、基板ホルダ汚染（所謂“チャック汚れ”）によって生ずる可能性が最も高い。一つのウエハ高さマップから、反復する露出領域（ダイ）からの高さマップ（トポロジー）を比較することもできる。平均高さマップに関して、あるダイに大きな差が生じたなら、ウエハ処理が基板テーブルによる焦点汚れを疑うことが出来る。ウエハ高さマップを比較する代りに、同じ比較をダイ当りの誘導露出経路、または以下に説明する焦点ずれパラメータMA、MSDまたは移動焦点について行うこともできる。あるダイまたはウエハが平均露出経路または焦点ずれパラメータから大きく外れるとき、焦点スポットも検出できる。

【0036】上に述べた解析は、全てウエハを露出する前に行うことが出来、且つウエハ排除（処理の影響）または基板ホルダ清掃（チャック汚れ）のような、修復作業を行うことが出来る。これらの方法で、焦点スポットレベルセンサ10の測定点の大きさに局限できる。これは、焦点スポット検出の従来方法より遙かに高い解像度を意味する。

【0037】

【実施例2】本発明の第2実施例を図8に示し、それは露出ステーションおよび測定ステーションだけ、並びに以下の議論に関連する部品だけを示す。この第2実施例は、上に説明した本発明のレベリング原理を、以下に説明するある改良と共に利用する。

【0038】図8の左の露出ステーションに、計測フレームMFに取付けた投影レンズPLがマスクMA上のTISマーカTIS-Mの像を、ウエハテーブルWTに取付けたセンサTIS上に投影するのを示す。この計測フレームは、この装置の他の部品からの振動の伝達から隔離し、微細計測および整列検知に使う受動的部品だけをその上に搭載する。この装置も最も敏感な測定素子の非常に安定なプラットフォームと成るように、この計測フレーム全体を、アンバーのような、熱膨張係数の非常に小さな材料で作ってもよい。この計測フレームMF上に取付ける部品には、ミラー34および35があり、それに、ウエハテーブルWTの側面に取付けた45°ミラー31によってZ干渉計の測定ビームZIFを導く。基板テーブルのZ位置をそのXの運動範囲に亘って測定できることを保証するために、ミラー34、35は、対応してX方向に大きな広がりを持つ。このZ位置をY運動の範囲に亘って測定できることを保証するために、ミラー31は、ウエハテーブルの全長をカバーする。やはり計測フレームMFに取付けられているのは、以下に詳しく説明する、信頼センサ20aのビーム発生および受取り部品21a、22aである。

【0039】測定ステーション（図8で右）で、同じ計測フレームMFが、露出ステーションのミラー34、35と同じ機能を果たすミラー33および32を担持し、ミラー32、33も、基板テーブルWTの必要な運動範囲に対応するために、露出ステーションと全く同じ、X方向の大きな広がりを持つ。ビーム発生部品11および検出部品12を含む、レベルセンサ10も計測フレームMF上に取付けられている。その上、本質的に露出ステーションの信頼センサ20aと同じ信頼センサ20bを備える。他の測定装置、例えば、整列モジュールも設けることができる。

【0040】上に議論したように、物理的参照面（この実施例でも、これをTISの上面によって与える）を使うことは、ウエハ高さマップをウエハステージに関連付け、それを二つのZ干渉計のゼロ位置、および上をウエハテーブルが動くベースプレート（石）BPの不平面度のようなある局部因子と無関係にする。しかし、ウエハ高さマップを測定ステーションでZ干渉計を使って作り、基板テーブル位置を露出ステーションでそこに設けた別のZ干渉計を使って制御するので、二つのZ干渉計間のXY位置の関数としての何らかの差がウエハ面を焦点面に配置する精度に影響することがある。本発明で使用する種類の干渉計システムでのこれらの変動の主因は、ミラー32、33、34、35の不平面度である。45°ミラー31は、ウエハテーブルWTに取付け、それが露出ステーションと測定ステーションの間で位置が換るとき、それと共に移動する。従って、これらのミラーの不平面度は、露出ステーションでの位置決めに測定ステーションと同じ程度影響し、十分に除去される。し

かし、計測フレームMF上に取付けたミラー32、33、34および35は、それらそれぞれの干渉計と共に滞留し、それに対応する対32、34および33、35の表面輪郭に差があれば基板テーブルWTの垂直位置決め精度に悪影響することがある。

【0041】確認センサ20aおよび20bは、この装置の初期設定に使い、その後定期的に必要に応じて使い、測定ステーションおよび露出ステーションでZ干渉計間の差を校正する。これらの確認センサは、ウエハの上面の垂直位置を、その下で基板テーブルを走査するときに、一つ以上の点で測定できるセンサである。信頼センサ20aおよび20bは、設計をレベルセンサ10と同じに出来るが、そうする必要はなく、並びに設定に（および稀な再校正に）だけ、生産ウエハでなく参照ウエハと共に使うので、設計基準が厄介でなく、これを利用して単純なセンサを設計できる。逆に、露出ステーションに投影レンズPLが存在することがそのステーションで確認センサに利用できる物理的位置を制限し、これも各確認センサの設計または選択に考慮する必要がある。確認センサを使う校正があらゆる露出の品質に影響するので、それらに高精度が要求される。

【0042】確認センサを使う校正プロセスでは、参照ウエハを基板テーブルに装填する。この参照ウエハは、裸のシリコンウエハであるのが好ましい。それが通常の裸のS1ウエハより幾らか平坦である要求はないが、その表面仕上げ（反射率の点で）これらの信頼センサに対して最適化するのが好ましい。この発明の好適実施例では、この参照ウエハがその反射率を最大にし且つ不平面度を最小にするように研磨するのが好ましい。

【0043】校正手順では、参照ウエハの部分高さマップ（通常通り物理的参照面に関係する）を測定ステーションでレベルセンサ10ではなく確認センサ20bを使って作る。これは、レベルセンサ10と同じ方法で行い；物理的参照面（TIS）を信頼センサのゼロ点に配置してZ干渉計をゼロにし、次にウエハを信頼センサの下で走査し、高さマップを確認センサとZ干渉計の読みとの間の差から作る。高さマップを露出ステーションでも、測定ステーションの高さマップと同じ点で信頼センサ20aを使って作る。この校正に対し、高さマップは、ウエハを完全に走査する必要はなく；ミラー32～35上のZ干渉計ビームの運動に対応するストリップをカバーする必要があるだけである。（これらのマップを作る順序は、ウエハが基板テーブル上で両方を行う間安定であれば、重要でない。）

【0044】これらのマップは、同じウエハを表すので、それらの間に差があれば、それらを作るために使った測定システム間の差によって生じたのだろう。二つの信頼センサは静的であり、それでそれらの高さマップへの影響は、位置依存性でなく、二つの高さマップの正規化および／または静的偏差の減算によって除去でき

る。残る差があれば、それは位置依存性であり、二つの高さマップを互いから引いて、露出ステーションZ干渉計を測定ステーションZ干渉計に関連付ける補正テーブル（ミラーマップ）を作ることができる。これらの補正テーブルは、計測フレームMFに取付けたミラー33、35および32、34間の差の結果であると考えることができ、それで生産プロセスで作ったウエハ高さマップに適用でき、またはマップを作るために使うZ干渉計の一つを補正するため若しくは露出中に基板テーブルを位置決めするために使うことが出来る。Z干渉計の精密な構造、特に計測フレームミラーおよび基板テーブルミラーによって、各干渉計システムのミラーの不平面度によって生ずるZ位置の差も1以上の自由度（Rx、Ry、Rz）で傾斜依存性かも知れない。この傾斜依存性をなくするためには、信頼センサを使って種々の異なる傾斜のウエハステージで幾つかの高さマップを作ることが必要かも知れず、それから、必要に応じて、多数の異なる補正テーブル（ミラーマップ）を誘導することが出来る。

【0045】オフアクシスレベリングの原理を説明したので、今度は第2実施例で使用するその幾らかの更なる改良、並びにその生産プロセスへの組み込み方法を説明する。図9および図10は、それぞれ、測定ステーションおよび露出ステーションで行う工程を示す。二つのウエハテーブルを使用するリソグラフィ装置では、一つのテーブルが図9の工程を行い、一方第2のテーブルは、それらを交換する前に、同時に図10の工程を行う。以下の説明で、単一ウエハの“寿命”は、測定ステーション（図9）から露出ステーション（図10）へ行き、戻るまで続く。

【0046】図9の工程S1に始まり、感光性レジストで塗被したウエハを基板テーブルWT上に装填する。（これは、一般的に、基板テーブルが干渉計システムIFの範囲外にある、測定ステーションと別の装填ステーションで行ってもよいことに注意すべきである。）このウエハテーブルを、干渉計計測システムの初期粗ゼロ合せが行えるように、一つ以上の位置検知装置（PSD）の捕捉範囲内へ動かす、工程S2。この初期粗ゼロ合せの後、干渉計システムの微細初期化／ゼロ合せが工程S3およびS4で続く。これら二つの工程は、（二つ以上の）物理的参照面上のレベルセンサ測定（“LS”で示す）を含み、それが参照平面（ウエハテーブルに固定した）を定め、それに関してウエハ高さマップを測定する。また、二つの整列測定（“AA”で示す）を同じ物理的参照面上に位置するマーカについて行い、ウエハテーブルに固定した水平参照位置を定める。S3およびS4でのこれらの測定は、この干渉計システムを全ての自由度で効果的にゼロ合せする。

【0047】このレベリング手順での次の工程は、大域レベル輪郭（GLS）と称するS5である。以下に更に

詳しく説明する、この工程では、ウエハ捕捉とウエハのレベルセンサによる初期走査を行い、その全体の高さおよび傾斜、並びに後の詳細走査がこのウエハに出入りする点でのその大體の高さを決める。この情報は、ウエハ高さマップ走査用基板テーブル径路を決められるようにする。

【0048】工程S6で、ウエハの大域整列を行う。ウエハ上の少なくとも二つの整列マーカを測定し(W1およびW2)、それらのXY位置がTIS基準上の参照マーカに関して決ったことを意味する。これは、ウエハを走査方向(y)に関して水平に回転する程度(Rz)を決め、ウエハ高さマップ走査を露出領域軸に平行に行う(即ち、“露出領域上を直進する”)ように、ウエハの回転を補正できるために行う。

【0049】その後、このレベリング手順は、処理依存補正(PDC)に必要な測定を続ける。処理依存補正は、レベルセンサのある形で必要であり、次に説明する。

【0050】ウエハ高さマップは、ウエハを露出する度毎に作らねばならない。もし、ウエハが既に一つ以上の処理工程を受けていれば、この表面層は、最早純粋な研磨したシリコンではなく、既にこのウエハ上に作った構造または既に作った形態を表すトポロジーもあるかも知れない。異なる表面層および構造がレベルセンサの読みに影響することがあり、特に、その直線性を変えることがある。もし、このレベルセンサが光学的であれば、これらの影響は、例えば、表面構造によって生ずる回折作用によるか、または表面反射率の波長依存性によるかも知れず、且つ常に予測不可能である。必要な処理依存補正を決めるためには、基板テーブルWTをレベルセンサ10の線形または線形化範囲に亘る幾つかの異なる垂直位置に設定して、露出領域またはダイをこのレベルセンサの下で操作する。ウエハ高さ、即ち、ウエハ表面と参照平面の間の物理的距離は、基板テーブルの垂直位置で変るべきでなく；それは、レベルセンサとZ干渉計の測定値を引くことによって得られる： $Z_{\text{WAFER}} = Z_{\text{LS}} - Z_{\text{IF}}$ 。従って、もし、 Z_{WAFER} の決定した値が基板テーブルの垂直位置で変らなければ、これは、レベルセンサまたはZ干渉計のどちらかまたは両方が線形でないか、等スケールでないことを意味する。Z干渉計は、ウエハテーブルおよび計測フレーム上のミラーを見るので、線形であると考えられ；実際、少なくとも一旦確認センサの使用によって決めた補正を適用すると、ウエハマップに必要な精度より高度に線形である。従って、ウエハ高さ値に差があれば、それはレベルセンサの非線形性またはスケール誤差から生じたと想定する。それら、およびそれらを観察したときのレベルセンサの読みの知識を使って、このレベルセンサの出力を補正することが出来る。このレベルセンサの現在好適な実施例では、単純なゲイン補正で十分であるが、他のセンサには更に複雑な補正

が必要かも知れないことが分った。

【0051】もし、処理すべきウエハがその上に別の処理を受けている露出領域を有するならば、このウエハ上の各異なる型式の露出領域に対して処理依存補正を決める。逆に、もし、同じまたは類似の処理を受けた露出領域を有するウエハのバッチを露出すべきなら、バッチ当たり1回各種の露出領域に対して処理依存補正を測定するだけでよいかも知れない。すると、その補正をその種類の露出領域の高さマップをバッチで作る度毎に適用できる。

【0052】多くのIC製造では、ウエハをリソグラフィ装置に装填する直前に、それに感光性レジストを付ける。これやその他の理由で、ウエハは、装填して適所にクランプしたとき、基板テーブルと異なる温度であるかも知れない。ウエハが基板テーブルと同じ温度に冷えた(または暖まった)とき、ウエハは真空吸引を使って非常にしっかりとクランプされているので、熱応力が生じることがある。これらは、ウエハの望ましくない歪みを生ずるかも知れない。熱平衡は、工程S2ないしS7が終るときまでに達していそうである。従って、工程S8で、ウエハの基板テーブルへの真空クランプを解放して、ウエハの熱応力を弛緩させ、次に再適用する。この弛緩は、ウエハの位置および/または傾斜に小さな変化を生ずるかも知れないが、工程S2ないしS4はウエハと無関係であり、S5およびS6は粗測定に過ぎないので、これらは許容できる。この段階でのウエハ位置の変化は、それがウエハの測定ではなく、レベルセンサの校正であるので、処理依存補正に影響しない。

【0053】真空を再適用後、以後、露出プロセスを完了し、工程S9でZマップを行うまで、それは再び解放しない。このZマップに必要な走査は、露出中にウエハを所望の精度で配置できるように、十分な点の高さを測定しなければならない。測定した点がウエハを露出すべき実際の領域をカバーすることも重要であり；印付けレーンおよび所謂ネズミのかみ傷のような、非露出領域に亘る測定は、誤解を招く結果を生ずるかも知れない。従って、高さマップ作成走査は、手元のウエハ上の露出領域の特定のパターンに最適化しなければならず；以下にこれを更に詳しく説明する。

【0054】一旦Zマップが完成すると、先行整列測定、工程S10を行ってから、工程S11で、基板テーブルを露出位置へ交換する。この先行整列プロセスでは、基板テーブルに固定したTIS基準(物理的参照面)上に位置する参照マーカに対する、ウエハ上の多数の整列マーカの位置を正確に決定する。このプロセスは、本発明に特には関連せず、それでここにそれ以上説明しない。

【0055】交換手順では、高さマップを作ったウエハを坦持する基板テーブルが露出ステーションに到達する。図10の工程S13。工程S14で基板テーブルの

粗位置決定を行い、もし必要なら、新しいマスクMAをマスクテーブルMTに装填する。工程S15。このマスク装填プロセスは、基板テーブル交換と同時に、または少なくとも始めてもよい。一旦マスクが適所にあり且つ粗位置決定、工程S14を行って終うと、工程S16でセンサTIS1を使って第1TIS走査を行う。このTIS走査は、上に説明したように、このTISが投影レンズの空中像焦点中に位置する、基板テーブルの垂直および水平位置を測定し、焦点面参照をもたらす。図9の工程S9で作った高さマップをTISが位置する物理的表面に関係付けるので、ウエハ表面を別の露出領域に対して焦点面に置くために必要な基板テーブルの垂直位置を直接誘導する。第2TIS走査、工程S17もセンサTIS2を使って行い、焦点面を参照するための第2点を得る。

【0056】一旦TIS走査を完了し、焦点面を決定すると、工程S19での任意に必要なシステム較正（例えば、レンズ加熱効果を補正するための調整）の後に、露出プロセスS18を行う。この露出プロセスは、一般的に一つ以上のマスクを使う複数露出領域の露出を伴う。複数のマスクを使う場合、マスク交換S20の後に、一つのTIS走査S17を繰返して焦点面変更を更新することが出来る。幾つかまたは全ての露出の間に、システム較正工程S19も繰返してよい。全ての露出の終了後、露出したウエハを担持する基板テーブルを、その間に図9の工程S1ないしS10を受けたウエハを担持する基板テーブルと工程S13で交換する。露出したウエハを担持する基板テーブルを装填ステーションへ動かし、新しいウエハを装填できおよびこのサイクルを再開できるように、露出したウエハを取出す。

【0057】図9の工程S9のウエハ高さマップ作成走査を説明するために、図11は、シリコン面積を最も良く使うようにウエハ上に配置した種々の形状および大きさの露出領域Cのパターンの例を示す。異なる露出領域Cは、印付けレーンSLによって分離し、“ネズミのかみ傷”として知られる、一般的に三角形の未使用領域が、必然的に矩形露出領域とウエハの曲線縁の間に残される。これらの印付けレーンは、一旦全ての生産プロセスが完了すると（異なるデバイスを分離するように）このウエハを切断するところであり、ある切断技術は、一方向の印付けレーンが全てウエハの幅全体に跨ることを要求するかも知れず；その場合、もしこの装置をステップ・アンド・スキャン・モードで使うべきなら、これらの全ウエハ幅印付けレーンを走査方向（例えば、Y方向）に平行に向けるのが都合がよい。これらの印付けレーンおよびネズミのかみ傷は、露出されないかも知れず、それでこのウエハが幾つかの処理工程または層の被着を受けた後に、それらは露出領域Cとは非常に異なる高さおよび表面特性を有するかも知れない。従って、露出する予定のないこれらの領域の高さ測定を無視するこ

とが重要である。

【0058】レベルセンサの現在好適な実施例は、例えば、九つの点（領域）で高さを同時に測定するために、走査方向に垂直に配置した九つの光学スポットの線形アレーを使用する。（Z干渉計データも対応するレベルセンサ点のアレーで基板テーブルの対応するZ位置データを与えるために内挿できることに注意すべきである。）このスポットのアレーは、この装置で露出できる最広露出領域の幅をカバーするに十分の大きさである。

【0059】現在好適な走査方式は、このアレーの中心スポットが露出領域の各列の中間線に沿って通るように、スポットのアレーを蛇行経路50で走査することであり；この中間線は、この露出プロセスで照明したスリットの中間線に対応する。この様にして作ったデータは、最少の再配置または計算で露出走査と直接関係付けることが出来る。この方法は、測定ステーションおよび露出ステーションの両方でZ干渉計ビームを基板テーブルに取付けたミラー31上の同じ位置に向けて走査を行うので、ミラー不平面度影響の一部もなくする。もし、ダイの列がレベルセンサのスポットのアレーより狭ければ、完全に露出領域内にないスポットから得たデータは無視する。レベルセンサの他の実施例では、スポットのアレーの幅を露出領域の幅に合わせるように調整することが可能かも知れない。

【0060】もし、ウエハのある露出領域の中心線が残りの中心線より走査方向と垂直な方向にずれているなら、修正走査方式を使うのが有利かも知れない。この状況を図12に示し、それは1行のダイEの中心線が残りのダイDからずれているのを示す。そのような場合、二つの蛇行経路を走査することによって、マップをより迅速に且つ基板テーブルに対して小さい加速度で作ることができる。図12に52で示す一つの経路は、1組の露出領域Dをカバーし、53で示す他の経路は他の領域Eをカバーする。勿論、露出領域の他の配列は、走査方式に更なる修正を要求するかも知れない。

【0061】ありそうなことだが、レベルセンサに限られた線形または線形化範囲を有する場合、基板テーブルWTをその下で、ウエハ表面をその範囲内に持込む垂直位置で走査しなければならない。一旦ウエハ表面を見付けてしまえば、ウエハ表面をこの線形または線形化範囲内に保つために基板テーブルWTの垂直位置を調整することは、レベルセンサの読みの基板テーブル位置決めシステムへの閉フィードバックループによって、簡単なことであるが、レベルセンサがウエハの外部から最初に露出領域上に動くときに、ウエハ表面を見付けることはそれ程簡単ではない。蛇行経路に、幾つかのそのような入点があり、図11の蛇行経路50上に参照数字51と矢印によって示し、問題を複合する。

【0062】入点51でウエハ表面を見付けるためには、主レベルセンサスポットアレーの前に捕捉スポット

を設けることが可能である。次に、ウエハ上のこの捕捉スポットの反射を、主スポットの場合より広い捕捉範囲を有する検出器へ導く。しかし、これは、追加のハードウェア：主スポットの両側（前／後）の捕捉スポットまたは1方向だけへの走査の制限を要する。必ずしも追加のハードウェアを要しない代替案は、基板テーブルを各入点近くに止め、ウエハ捕捉を行い、およびウエハ表面をレベルセンサの線形または線形化範囲で測定してウエハ表面位置をこの入点で近似することである。しかし、これは、この測定手順をかなり遅くし、スループットの点からは望ましくない結果かも知れない。

【0063】この発明のこの実施例では、これらの問題を、ウエハ表面を捕捉してから上述の大域レベル輪郭走査（図9の工程S5）を行うことによって避ける。この大域レベル輪郭走査を図13を参照して更に説明する。

【0064】この大域レベル輪郭走査のためには、最初に露出領域C内の都合の良い点（縁に近いのが好ましい）が単一捕捉スポットおよびレベルセンサ（スポットアレー）の主スポットの下にあるように基板テーブルを配置する。例えば、ウエハ表面を捕捉して主スポットの線形または線形化範囲内に来るまで基板テーブルを走査することによって、ウエハ表面を見付け、次に中央スポット41が全露出領域の周囲の内部の周りの経路60を横切るように基板テーブルを走査する。この捕捉手順を以下に詳しく説明する。ウエハ表面高さの測定は、この走査の周りの決った位置で行う。中心スポットは勿論、このアレーの他のスポットがウエハ（の露出領域）の上に当たる場合、この中央スポットは勿論、これらのスポットからの測定も行うことが出来る。しかし、測定は、露出領域の外に当たるスポットから行うべきでない。図示するように、大域レベル輪郭経路60は、露出領域の縁をかなり接近して追従する曲りくねった経路である；しかし、より滑らかな経路も使って良く、特に、ウエハに露出領域が良く詰まっているときは、円形コース61で十分であり、より便利かも知れない。この大域レベル輪郭は、ネズミのかみ傷の上を通る円として配設してもよく、その場合、ネズミのかみ傷の上の測定は行わず、またはネズミのかみ傷の上で行った測定のデータは、ウエハの大域高さおよび傾斜の計算には無視する。

【0065】大域レベル輪郭走査で集めたデータは、二つの目的で使用する。第1に、後に行うべき高さマップ作成走査の入点51（図11参照）付近でウエハ高さに関連するデータは、入点51でのウエハ高さを予測するために使用して、マップ作成走査中、ウエハ表面位置を線形または線形化レベルセンサ範囲内に入れるために基板テーブルを正しい高さに出来るようにする。大抵の場合、このためには僅かなデータ点しか要らず、しかも内挿または外挿によってウエハ高さの十分に正確な予測を可能にするためには入点に特に近い必要もない。このレベルセンサは、（好ましくは）全て線形または線形化範

囲内とする必要がある、スポットのアレーをX方向に有するので、高さマップ作成走査用に入点51での局部Ry傾斜を知ること望ましい。もし、大域レベル輪郭走査が何れかの入点付近でY方向に平行であるか、または平行に近ければ、単一スポットだけから得たデータを使ってRy傾斜を正確に決めることは出来ない。以下に説明するように、X方向に離間した測定スポットのアレーを有するレベルセンサを使う場合、複数スポットからのデータを使って局部Ry傾斜を決めることが出来る。勿論、もし、アレーの一部が露出領域外に出るのであれば、その領域内にあるスポットからのデータを選択する。

【0066】大域レベル輪郭データの第2の用途は、全ウエハのために大域、または平均、高さおよび傾斜（2軸周りの）を決めることである。これは、集めたウエハ高さデータに最も良く適合する平面を決めるために、既知の数学的手法、例えば、最小自乗法によって行う。もし、この大域傾斜（ときには“ウエッジ”と称する）が所定の値より大きいならば、これは装填手順が正しくないことを十分示すかも知れない。その場合、再試行のためにウエハを取出して再装填することが出来、もし失敗し続けるなら排除することさえ出来る。この大域高さおよび傾斜情報を使って、ウエハ上の整列マーカの、基板ステージ上の参照マーカに対する空間関係を正確に決めるために図9の工程S10で使う先行整列センサを集束する。この先行整列センサおよびプロセスは、WO98/39689（P-0070）に詳細に記載してある。

【0067】ウエハマップ走査中、レベルセンサ10は、基板テーブルへ連続ZおよびRyフィードバック信号を提供し、レベルセンサ10をその線形または線形化範囲に維持する。もし、このフィードバックループが止る（レベルセンサ10が正しい数を生給しない）と、大域ウエハウエッジ（大域RxによるZ輪郭）に対応する経路を追従することによってテーブルを制御する。

【0068】レベルセンサ10の現在好適な実施例を図14に示し、付加的に、このセンサの動作の態様を示す図14Aないし図14Gを参照して以下に説明する。

【0069】レベルセンサ10は、測定ビームb1sをウエハW（または物理的参照平面の垂直位置を測定するときはそれ、若しくはその他の反射面）上に向けるビーム発生ブランチ11およびウエハ表面の垂直位置に依る、反射されたビームの位置を測定する検出ブランチ12を含む。

【0070】このビーム発生ブランチでは、光源111によって測定ビームを発生し、その光源は、発光またはレーザダイオードのアレーでも、または他で発生して光ファイバによって“照明器”111へ送ってもよい。光源111が出すビームは、特に幾つかの処理工程終了後、ウエハ表面からの干渉効果の波長依存性を平均するように、広帯域波長、例えば、600ないし1050nm

mを含むのが好ましい。照明光学系112は、レンズおよびミラーの何か適当な組合せを含んでもよく、光源111が出す光を集め、投影格子113を均一に照明する。投影格子113は、図14Aに詳細に示し、別々の／個々のスポットを作るために格子線をその軸に平行にして分割してもよい細長い格子113a、およびウエハ上にこれらの主検出スポットアレーの前に捕捉スポットを作る追加の開口113bから成る。この格子の周期は、このウエハ表面位置を測定すべき精度によって一部決められ、例えば、約 $30\mu\text{m}$ でもよい。ウエハ上に投影される格子線が何れの座標軸に対しても平行でないように、この投影格子をその光軸周りに僅かに回転して配置し、それによってxまたはy方向に沿うウエハ上の構造との干渉を避ける。投影レンズ114は、投影格子113の像をウエハW上に投影するテレセントリック系である。投影レンズ114は、投影した像の色収差を最小にしたまたは避けるように、本質的に反射光学素子またはそれだけから成るのが好ましく；それは投影ビームが広帯域であり、屈折光学系ではそれらを容易に除去または補償出来ないからである。折返しミラー115、116を使って投影ビームb_{is}を投影レンズ114に出し入れし、このビーム発生ブランチの部品の都合のよい配置を可能にする。

【0071】投影ビームb_{is}は、ウエハに法線に対して、例えば 60° ないし 80° の範囲のかなり大きな角度 α で入射し、検出ブランチ12へ反射する。図14Bに示すように、もしウエハ表面WSの位置が距離 Δh だけ位置WS'へ移動すると、反射ビームr'は、ウエハ表面の移動前のビームrに対して距離 $2 \cdot \Delta h \cdot \sin(\alpha)$ だけ移動する。図14Bは、ウエハ表面上の像の外観も示し；入射角が大きいので、この像は格子線に垂直に拡がる。

【0072】反射ビームを検出光学系121によって集め、検出格子126上に集束し、その格子は、本質的に投影格子113の複製であり、このスポットーアレーパターンに対応するように細分する。検出光学系121は、投影光学系114と直接相補であり、色収差を最小にするために本質的に反射光学素子またはそれだけから成る。再び折返しミラー122、123を使って部品の配置を都合よくしてもよい。検出光学系121と検出格子126の間に、光を 45° に偏光する線形偏光子124、並びに格子線に垂直なずれを大きさでこの光の水平および垂直偏光成分間の格子周期に等しくする複屈折結晶125が位置する。図14Cは、この複屈折結晶がないときの検出格子126でのビームを示し；それは、一連の交互する明帯域と暗帯域で、明帯域が 45° 偏光されている。複屈折結晶125は、水平偏光成分の明帯域が垂直偏光成分の暗帯域を埋めるように、水平および垂直偏光状態を変える。従って、図14Dに示すように、検出格子126での照度は、均一なグレーであるが、交

互する偏光状態のストリップを有する。図14Eは、ウエハ表面の垂直位置に依る、このパターンに載せた検出格子126を示し；ウエハが称呼ゼロ垂直位置にあるとき、検出格子126が一つの偏光状態、例えば、垂直の明帯域の半分と他の状態の半分以上を覆い閉塞する。

【0073】検出格子126を通過した光を変調光学系127によって集め、検出器128上に集束する。変調光学系は、二つの偏光状態を交互に通すように、例えば、約 50kHz の周波数の、交番信号によって駆動する偏光変調装置を含む。従って、検出器128が見る像は、図14Fに示す二つの状態の間を交互する。検出器128は、高さを測定すべきスポットのアレーに対応する多数の領域に分割する。検出器128のある領域の出力を図14Gに示す。それは、周期が変調光学系のそれに等しい交番信号であり、この振動の振幅は、検出格子126上の投影格子の反射像の整列程度、従ってウエハ表面の垂直位置を示す。上述のように、もしウエハ表面が称呼ゼロ位置にあれば、検出格子126は、垂直偏光状態の半分と水平偏光状態の半分以上を遮断し、それで測定した強度が等しく、検出器領域による振動する信号出力の振幅はゼロだろう。ウエハ表面の垂直位置がこのゼロ位置から動くと、検出格子126は、水平偏光帯域の多くを通し、垂直偏光帯域の多くを阻止し始める。すると振動の振幅が増すだろう。ウエハ表面の垂直位置の尺度である、この振動の振幅は、ウエハ表面の垂直位置にナノメータで直接線形には関係しない。しかし、補正表または公式を、校正したZ干渉計および未校正のレベルセンサ10を使って、裸のシリコンウエハの表面の一定の高さを基板テーブルの種々の異なる垂直位置で測定することによって、この装置の初期設定（およびもし必要なら定期的に再校正した）で容易に決めることができる。

【0074】レベルセンサおよびZ干渉計の測定を同時に行なったことを保証するために、同期バスを設ける。この同期バスは、この装置のマスタークロックが発生した非常に安定な周波数のクロック信号を伝える。レベルセンサとZ干渉計の両方をこの同期バスに接続し、このバスからのクロック信号を使ってそれらの検出器のサンプリング点を決める。

【0075】投影格子113を通過した捕捉スポット113bが検出格子を通り、そこでそれは、図15Aに示すように、二つ131、133は高く設定し、一つ132は低く設定した、三つの異なる検出領域に入射する。この低検出領域からの出力を高検出領域から出力から引く。これらの捕捉スポット検出器領域は、ウエハ表面がゼロ位置にあるとき、捕捉スポットが高・低検出領域に同等に当たり、引いた出力がゼロであるように配設する。ゼロ位置から離れると、捕捉スポットが検出領域の一つに他より多く当たり、引いた出力の大きさが増し、その符号は、ウエハが高過ぎるか低過ぎるかを示す。引いた検出器出力d_{cap}の基板テーブル位置Z_{IF}への依存性を図

15に示す。検出器出力のこの形は、従来のサーボフィードバックより迅速なゼロ捕捉方法を可能にする。“move-until”と称する、この改善した方法によれば、捕捉スポット検出器がウエハ表面の高過ぎまたは低過ぎを示すとき、基板テーブルのZ位置アクチュエータが、このウエハ表面を主レベルセンサアレーの線形または線形化範囲内に入れるためにこのステージを適当な方向に動かすように指示する。このウエハステージの運動は、捕捉スポット検出器の出力がトリガレベル t_h または t_l を通過するまで続き、その方向に従ってそれが移動する。トリガレベルを横切ると、この装置の制御装置にZ位置アクチュエータへ命令を出させ、ブレーキ手続を始める。これらのトリガレベルは、この応答時間およびステージ運動にブレーキを掛けるために要する時間中に、このステージがゼロ位置へ動き、または接近するように設定する。その後、このステージを、より正確な主レベルセンサスポットの制御の下でゼロ位置へもたすことが出来る。これらのトリガ点は、このステージの動力学に従って決め、ゼロ検出器出力の周りに対称に離間する必要はない。この“move-until”制御方式は、線形測定システムを要することなく、迅速且つ頑丈なゼロ捕捉を可能にし、他の状況に使える。

【0076】上に説明したレベルセンサは、その性能を改善するために更に最適化できる。走査(Y)方向の精度の改善は、適当な信号フィルタリングによって行うことが出来、これは、部分的に処理したウエハ上に見られる特定のプロセス層に適合させてもよい。全方向の追加の改善(特定のプロセス層に対する)は、照明光学系112を(投影格子113上の照明光の均一性および/または角分布を調整するために)変えることによって、投影格子113を変えることによって、または検出システム(検出器の大きさ、位置および/または角分解能並びに検出器数)を調整することによって得てもよい。

【0077】信頼センサ20a、20bの現在好適な形を図16および図17に示す。ビーム発生ブランチ21は、限られた帯域幅の光を出す光源211(例えば、ソリッドステート・レーザダイオードまたはスーパーミネセントダイオード)を含む。それは、計測フレームから離れて位置し、その出力を光ファイバ212によって所望の点へ持ってくるのが都合がよい。この光をファイバ終端器213から出力し、コリメータ光学系214によってビームスプリッタ215上に向ける。ビームスプリッタ215は、二つの平行測定ビーム

【外1】

b_{c01} および b_{c02}

を作り、それらをウエハW上のそれぞれのスポット23を均一に照明するためにテレセントリック投影光学系216によって集束する。この信頼センサの測定ビームの帯域幅は限られるので、投影光学系216は、都合よく屈折性素子を使うことが出来る。検出光学系221が反

射されたビームを集め、それらを、検出器223、224と検出光学系221の間に位置する検出プリズム222の縁に集束する。検出プリズム222と検出器223の側面図である図17に示すように、測定ビームは、検出プリズム222の背面に入射し、傾斜面222a、222bから出る。検出器223は、二つの検出器素子223a、223bから成り、検出プリズム222の面222aから出る光が検出器素子223aに達し、面222bから出る光が検出器素子223bに達するように配置されている。検出器224は、同様である。検出器素子223aおよび223bの出力は、強度で評価し、減算する。ウエハ表面がゼロ位置にあるとき、これらの測定ビームが検出プリズム222の面222a、222b上に対称に当り、等量の光を検出器素子223a、223bに向ける。次に、これらが同等の出力を生じ、それで減算した出力がゼロになる。ウエハ表面がこのゼロ位置から動くと、反射したビームの位置は、上下し、面222a、222bの一つに他より多く当り、それぞれの検出器素子により多くの光を向ける結果となり、それで減算した出力が比例して変る。ウエハの傾斜は、検出器223および224の出力の比較によって決めることが出来る。

【0078】この配置は、本発明の第2実施例で、並びに他の用途で確認センサとして使える、簡単で頑丈な高さおよびレベル検出器をもたす。この確認センサは、主として測定および露出ステーションのZ干渉計の初期設定および定期的、例えば、月単位の再校正を意図する。しかし、上に説明した確認センサは、基板テーブルWTに対する投影レンズPLの焦点面の位置の精密な決定に使うTISより広い捕捉範囲および迅速な応答を有する。従って、確認確認センサ20aは、基板テーブルを最初に露出ステーションへ交換するとき、TISの垂直位置の粗い決定をするために有利に使うことが出来る。この確認センサによって測定した高さを先に測定した最善焦点整合位置と関係付け、この最善焦点面の期待する位置に近いTIS走査のための出発点および範囲を予測するために使う。これは、上に説明したTIS走査を短く、従って迅速に出来、スループットを改善することを意味する。

【0079】これらの確認センサに使用できるビームスプリッタ215を図18に示す。ビームスプリッタは、同じガラスからの、および好ましくは等しい厚さの多数のプリズムから成る。三つのプリズム51、52、53から成るビームスプリッタを使って、基本動作原理を説明する。プリズム51は、断面が台形で、入力ビーム54がその上面55の片側近くに入射する。入力ビーム54の位置は、それがこの上面55と45°の第1プリズム51の一側面56に当るようになっている。第2プリズム52は、第1プリズム51の側面56に接合され、この入力ビームの所望の部分(本実施例では半分)が第

2プリズム52の中へ直入してビーム57を形成し、一方残りは第1プリズム51内で水平に反射してビーム58を形成するように、この継目を塗被する。第1プリズム51で反射されたビーム58は、そのプリズムの第1側面56と平行な第2側面59に当り、下方に反射され、第1プリズム51の下面を出て、第1プリズム51の上面と平行な、第3プリズム53の上面および底面を通る。第2側面59は、ビーム58の全内部反射を保証するために、必要に応じて塗被してもよい。第2プリズム52に入るビーム57は、第1プリズム51の側面56に垂直な、第2プリズム52の二つの平行面によって内部反射され、第1プリズム51の上面55と平行な、第2プリズム52の底面から出る。それによって、ビーム57および58は、平行であるが離れて出力される。ビーム57、58間の離隔距離は、プリズム51および52の大きさによって決る。プリズム53は、ビーム57、58用の結像光学系を同じに出来るように、両ビームの光路長を均等化するために設ける。プリズム53は、図示のようにプリズム52も支持するが、これはある用途では必要ないかも知れない。プリズム52および53が接する面でのビーム57の反射を向上するために、空隙を残し、または適当な被膜を設けてもよい。

【0080】ビームスプリッタ50は、簡単で、頑丈で、作るのが容易である。それは、平行（従来の立方体ビームスプリッタが垂直ビームをもたらすのに対して）で光路長が等しい出力ビームをもたらす。この分割面は、偏光選択式に、またはそうでなくで、後者の場合、入力ビーム強度を所望により均等にまたは不均等に分割することができる。

【0081】ウエハ表面WSとレベルセンサ10の測定スポットの焦点面の交差によって定められるZ方向に垂直な軸周りのウエハステージの傾斜に鈍感であることが、上に説明したレベルおよび信頼センサ、並びにその他の光学的高さセンサの特徴である。これは、これらのセンサがスポットの合焦軸まで外挿した測定スポットの領域に亘って高さを測定するという事実による。この傾斜鈍感性は、Z干渉計および光センサをXY平面で互いの方へ較正するために使うことができる。そのような構成のための手順を図19およびレベルセンサを参照して説明するが、類似の手順を確認センサまたはその他の類似の光センサに使うことができる。

【0082】基板テーブルの位置決めシステムを、このZ干渉計がその一部である多軸干渉計システムに結合し、離間したZアクチュエータを使ってXY平面の選択した軸の周りに回転を加えるように設定できる。このZ干渉計測定位置をレベルセンサ測定スポットと整列するために、この位置決めシステムを使ってこのステージを、このZ干渉計測定位置を通り、例えば、Y軸に平行な軸周りに回転する。Z干渉計によって測定したこのテーブルのZ位置は、この傾斜中変わらないままである。も

し、レベルセンサとZ干渉計を正確に整列すると、ウエハ表面位置も変わらないままである。しかし、図19に示すように、レベルセンサ測定位置がZ干渉計位置から量 δX だけずれていて、基板テーブルWTをその図で仮想線で示す位置へ傾斜すると、レベルセンサ出力に変化 δW_s を生ずるだろう。従って、位置ずれ δX 、およびY方向の位置ずれ δY は、Z干渉計位置を通過する二つの、好ましくは垂直な軸周りの傾斜によるレベルセンサ出力の変化を検出することによって迅速に決めることができる。そこで、この干渉計測定位置がレベルセンサ測定位置と正確に対向することを保証するように、この干渉計システムまたはレベルセンサ10のパラメータを調整することができる。

【0083】レベルセンサが測定スポットのアレーを使う場合、これらのスポットが正確に整列されていることが常に保証される筈がない。従って、上記の手法を使って、Z干渉計位置に関する称呼位置からの個々のスポットの位置ずれを決めることができる。次にこの情報を使って高さマップまたはレベルセンサ出力を補正できる。

【0084】

【実施例3】第3実施例は、第1実施例のレベリング原理を使用し、それで以下に説明することを除いてその実施例と同じである。この第3実施例は、上に説明した第2実施例のハードウェアおよび改良も使ってよい。しかし、この第3実施例は、露出経路の最適化のために改善した方法を使用する。これを以下に図20を参照して説明する。

【0085】上に議論したように、基板ステージが固定で、実際に動くのはウエハであるが、露出スリット像が動くと考えるのが都合がよく且つ妥当である。以下の説明は、この観点から行う。

【0086】図20は、以下で使う表記法を示す。明瞭さのために図20ではスリット像SIをウエハ表面から離して描くが、この最適化手順の目的は、露出中スリット像の焦点面が出来るだけウエハ表面と一致することを保証することであることに注意すべきである。表面が $w(y)$ によって定義される1次元ウエハおよびスリット像SIを考えると、このウエハ上の座標に対応する移動平均（経時）焦点ずれ $MA(y)$ は次のように計算できる：

【数2】

$$MA(y) = \frac{1}{s} \int_{-\frac{s}{2}}^{\frac{s}{2}} [w(y) - \{z(y+v) - vR_x(y+v)\}] dv \quad (2)$$

但し、この積分は、走査方向のスリットサイズ s に亘って行い、被積分関数 $w(y) - [z(y+v) - vR_x(y+v)]$ は、ある瞬間のウエハの点上の焦点合せ誤差である。同様に、ウエハ上の点に対する移動標準偏差は次のように定義でき：

【数 3】

$$MSD^2(y) = \frac{1}{s} \int_{-\frac{s}{2}}^{\frac{s}{2}} [w(y) \{x(y+v) - vR_x(y+v)\} - MA(y)]^2 dv \quad (3)$$

それは、ウエハ上のその点の実際の露出中の焦点ずれ時間変動である。露出スリット像の平面とウエハの間の差を最小にするためには、2次焦点ずれ項を使って、次のように定義する：

$$MF^2(y) = MA^2(y) + MSD^2(y) \quad (5)$$

【0087】これは、露出経路の最適化および露出領域に亘る移動焦点の最小化で、時間、従って走査積分を無視する第1実施例の単純な最小自乗法最適化と違って、移動平均および移動標準偏差の両方を考慮に入れることを意味する。式(3)および(4)は、 $R_y(t)$ 依存性を加え、MFを $-W/2$ から $W/2$ までのXについて積分することによって容易に2次元に拡張でき、但しWはX方向のスリットの幅である。この最適化を計算するためには、周波数領域表現を使うのが便利である。周波数領域での計算は、露出経路が基板テーブル位置決めシステムの性能に対して最適化されるように、幾つかまたは全ての自由度で過剰の基板ステージ加速度を生ずる結果になるであろう、設定点の高周波変動を濾過して除外けるようにもする。

【0088】上の議論では、露出スリット像の最適焦点が平面と一致すると仮定したが；これは必ずしもそうではなく；実際は最適焦点が任意の面にあって、所謂焦点面偏差(FPD)を生ずるかも知れない。もし、露出スリット領域上のその面の輪郭を、焦点マップ $f(x, y)$ を作るためにTISを使って測定または計算できたなら、ウエハ運動を実際の最適上纏綿に対して最適化するように、出来たデータまたは式を上の式に加えることが出来る。

【0089】この第3実施例の最適化手法は、走査システムに対するよりよい焦点合せおよびより滑らかな基板ステージ経路に終ることが出来、スループットおよび得率を増す。

【0090】

【実施例4】第4実施例では、レベルセンサがウエハ表面位置の測定で、レジスト層の上面によって反射されたビームとレジスト層の中へ屈折してその底面によって反射されたビームの間の干渉によって生ずるかも知れない誤差を打消すための付加的特徴を備える。さもないければ、この第4実施例は、上に説明した第1ないし第3実施例の何れかと同じかも知れない。

【0091】上記上面および底面から反射されたビームの干渉は、測定ビームの光学波長および入射角は勿論、レジスト特性およびウエハ表面特性に大きく依存する。広帯域光源および検出器がそのような単一波長干渉を平均するために現在使われている。もし、ウエハ表面位置

【数 4】

$$MF^2(y) = \frac{1}{s} \int_{-\frac{s}{2}}^{\frac{s}{2}} (w(y) \{x(y+v) - vR_x(y+v)\})^2 dv \quad (4)$$

ここでMF(y)を移動焦点と呼ぶ。MF(y)をMA(y)およびMSD(y)の項で次のようにも書ける：
【数 5】

をスペクトル分解した方法で測定し、それによって広帯域測定ビームの多数の波長に対して別個の測定を行うならば、この平均化原理の改善を実現できる。これを達成するためには、ウエハ表面位置の測定用に時間的または空間的に分離した波長(色)システムを作ることが必要である。これは、レベルセンサの測定原理に以下のような変更を必要とする。

【0092】レベルセンサへの第1の可能な変更は、連続広帯域光源を異なる波長範囲(色)の光ビームを選択的に発生できるもので置換えることである。これは、例えば、レベルセンサの照明システムの適当な点に異なるカラーフィルタ(例えば、カラーセル上の)を選択的に介在させることにより、幾つかの独立に選択可能な光源を使うことにより、波長を調整できる光源を使うことにより、または小さい広帯域ビームの中にある回転/振動プリズムからの選択したビーム部分を使うことにより達成できる。次に、このレベルセンサを使って、測定ビームの異なる波長の光を使い、各点でウエハ表面の幾つかの測定を行う。

【0093】もう一つの選択は、広帯域検出器を異なる波長範囲(色)の光を選択的に検出できるもので置換えることである。これは、例えば、検出器の前の検出光学系にカラーフィルタを配置することにより、プリズムを使って測定ビームを異なる波長に空間的に分割し、それからこの異なる波長のビームを別々の検出器で検出することにより、またはウエハ表面位置を測定するために広帯域反射ビームをスペクトルで解析するその他の方法により達成できる。

【0094】当然、組合せアプローチを使い、それによって投影システムと検出システムの両方をスペクトル分解するようにすることも可能である。

【0095】干渉効果がなければ、各測定(各波長に対する)が同じ結果を出すべきであり；従って、そのような測定で、もし違う結果を得たならば、これは、上の最初の段落で触れたような効果の存在を示す。そこで、多種多様な手法を使って、改良したウエハ表面位置測定を導き出すことが出来る。例えば、矛盾する結果は、補正または破棄してもよい。過半数投票の手法も使ってもよい。その代りに、ウエハ表面位置のスペクトル計測に基づいて、レジストおよびウエハ表面特性のスペクトル応

答を記述するモデルによって実際の位置を誘導してさえよい。

【0096】記述した干渉効果は、ウエハ表面上の測定ビームの入射角にも依るので、この効果を評価し、次いでそれを補正するように、この入射角も変えたいかも知れない。従って、レベルセンサへの更なる可能な変更は、それをウエハ表面位置が異なる入射角で測定ビームを使って行えるようにすることである。これを達成する一つの方法は、ウエハ上の同じスポットであるが、別々の投影および検出光学系に対して異なる入射角を有する多重測定ビームを形成することである。その代りに、同じ投影および検出システムが種々の測定ビームに関係した異なる光軸を包含するように光学系を変えることが出来る。時間的に変動する入射角を作るもう一つの選択は、レベルセンサの光学系に回転／並進折返しミラー（またはその他の可動部品）を使うことである。

【0097】上に説明した波長依存性同様、干渉効果がなければ、異なる入射角での測定が同じ結果を出すべきである。従って、矛盾（入射角での変動）があれば、避け、補償し、または同じ方法でモデル化できる。

【0098】上記の付加的特徴および改善は、勿論、一緒にまたは別々に、およびここに説明した以外の光学センサに使ってもよい。

【0099】

【実施例5】この発明の第5実施例を図21に示す。この発明の第5実施例は、露出放射線として、例えば、9ないし16nmの範囲の波長の極紫外線（EUV）、および反射性マスクMA'を使用するリソグラフィ装置である。少なくとも機能的に、この第5実施例の部品は、一般的に第1実施例のものと同一であるが、それらは使用する露出放射線波長に適合するようにされ、それらの配置は、反射性マスクの使用によって必要とされるビーム経路に適応するように調整されている。必要かも知れない特別の改作には、照明および投影光学系IL'、PL'を露出放射線の波長に最適化することがあり；これは、一般的に屈折性ではなく反射性の光学素子を使うことを伴う。EUV放射線に使う照明光学系IL'の例は、ヨーロッパ特許出願第00300784、6号（P-0129）に記載されている。

【0100】反射性マスクを使うリソグラフィ装置と透過性マスクを使うものとの間の重要な差は、反射性マスクではマスクの不平面度が、下流の光学系、即ち、投影レンズPL'の光路長によって増加する、ウエハ上の位置誤差になることである。これは、マスクの高さおよび／または傾斜偏差がマスク上の照明ビームの有効入射角を局部的に変え、従ってウエハ上の像形態のXY位置を変えるからである。

【0101】この発明の第5実施例によれば、マスクの不平面度の影響は、露出に先立ってマスクの高さマップを作り、露出中にZ、RxおよびRyの少なくとも一つ

でのマスク位置を制御することによって回避または軽減される。この高さマップは、上に説明したのと類似の方法（即ち、測定ステーションでのマスクのオフアクシスレベリング）で作れるが；しかし、それを露出ステーションのマスクで作ってもよく、それは高さマップを物理的参照面に関連付ける必要を無くするかも知れない。露出または露出走査（露出経路）中のマスクの最適位置の計算は、上に説明したのと同等でよいが、それをウエハおよびマスク露出経路の最適化と結合してもよい。しかし、マスクに対しては、傾斜偏差がウエハでの位置に大きな影響を有するので、その最適化計算に重きを置いた方が有利かも知れない。

【0102】この発明によるリソグラフィ投影装置は、二つ（以上）の基板テーブルおよび／または二つ（以上）のマスクテーブルを含んでもよいことにはっきりと注目すべきである。そのようなシナリオでは、第1基板テーブル上の第1基板が測定ステーションで高さマップ作成を受け、一方第2基板テーブル上の第2基板が同時に露出ステーションで露出を受け；および複数マスクテーブルの場合、同様であることが可能である。そのような構成は、スループットを非常に大きくすることが出来る。

【0103】この発明は、基板レベリングだけ、マスクレベリングだけ、または基板レベリングとマスクレベリングの組合せに適用できることにもはっきりと注目すべきである。

【0104】上にこの発明の特定の実施例を説明したが、この発明を説明したのと別の方法で実施してもよいことが分るだろう。この説明は、この発明を限定することを意図しない。

【図面の簡単な説明】

【図1】この発明の第1実施例によるリソグラフィ投影装置を示す。

【図2】レベルセンサおよびZ干渉計による測定からウエハ高さを決める方法を示す図である。

【図3】本発明によるオフアクシスレベリング手順の種々の工程を示す図である。

【図4】本発明によるオフアクシスレベリング手順の種々の工程を示す図である。

【図5】本発明によるオフアクシスレベリング手順の種々の工程を示す図である。

【図6】本発明によるオフアクシスレベリング手順の種々の工程を示す図である。

【図7】本発明によるオフアクシスレベリング手順で使用するセンサおよび基準を示す基板テーブルの平面図である。

【図8】この発明の第2実施例の露出ステーションおよび測定ステーションの側面図である。

【図9】この発明の第2実施例の測定出ステーションで実施する測定プロセスの種々の工程を示す流れ図であ

る。

【図 10】本発明の第 2 実施例の露出ステーションで実施する露出プロセスの種々の工程を示す流れ図である。

【図 11】本発明の高さマップを測定するために使用できる走査パターンを示す線図である。

【図 12】本発明の高さマップを測定するために使用できる代替走査パターンを示す線図である。

【図 13】本発明の第 2 実施例の大域レベル輪郭プロセスを示す線図である。

【図 14】この発明に使用できるレベルセンサの現在好適な実施例の構造を示す。

【図 14 A】この発明に使用できるレベルセンサの投影格子を詳細に示す。

【図 14 B】この発明に使用できるレベルセンサの動作態様を示す。

【図 14 C】この発明に使用できるレベルセンサの検出格子の動作態様を示す。

【図 14 D】この発明に使用できるレベルセンサの検出格子の動作態様を示す。

【図 14 E】この発明に使用できるレベルセンサの検出格子の動作態様を示す。

【図 14 F】この発明に使用できるレベルセンサの検出器の動作態様を示す。

【図 14 G】この発明に使用できるレベルセンサの検出器の出力を示す。

【図 15】図 14 のレベルセンサの捕捉スポットの検出器出力対基板テーブル位置を示すグラフである。

【図 15 A】図 14 のレベルセンサの捕捉スポット用検出器部分を示す線図である。

【図 16】この発明の第 2 実施例に使用できる信頼センサの現在好適な実施例を示す線図である。

【図 17】この発明の第 2 実施例に使用できる信頼センサの現在好適な実施例を示す線図である。

【図 18】図 16 および図 17 の信頼センサに使用できるビームスプリッタの線図である。

【図 19】この発明の実施例に使用できる Z 干渉計較正手順を説明するために使用する線図である。

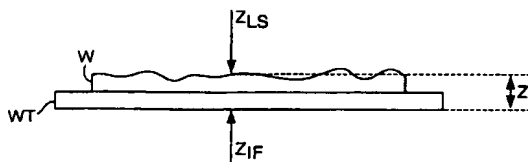
【図 20】この発明の第 3 実施例による露出経路最適化手順を説明する際に使用する表記法を示す線図である。

【図 21】この発明の第 5 実施例によるリソグラフィ投影装置を示す。

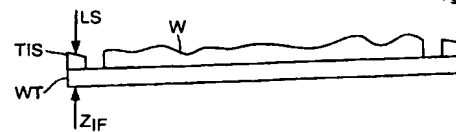
【符号の説明】

- C 目標部分
- CO コンデンサ
- Ex ビーム成形光学素子
- IF 位置検出手段
- IL' 照明光学系
- IN インテグレータ
- LA 線源
- MA マスク
- MA' 反射性マスク
- MT マスクテーブル
- PB 投影ビーム
- PL 投影システム
- PL' 投影システム
- W 基板
- WT 基板テーブル
- 10 レベルセンサ
- 20 a 第 1 位置検出システム
- 20 b 第 2 位置検出システム
- 111 放射線源
- 113 投影格子
- 114 投影光学系
- 121 検出光学系
- 126 検出格子
- 128 検出器

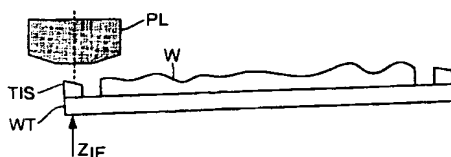
【図 2】



【図 3】



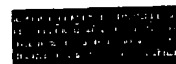
【図 5】



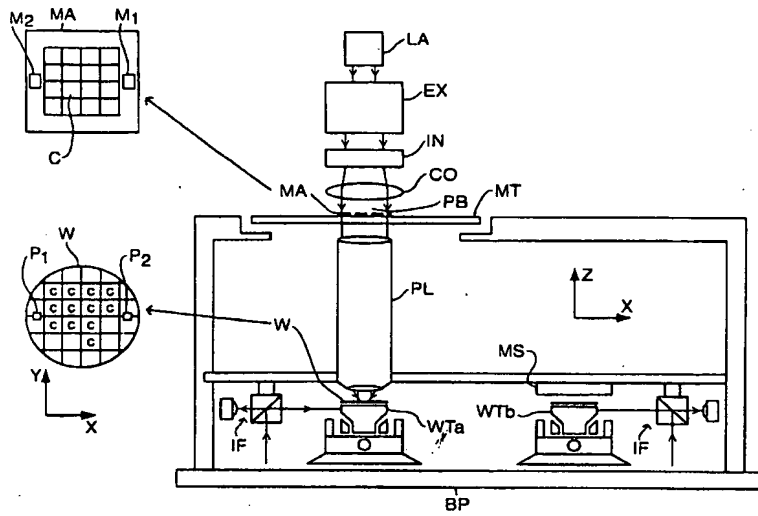
【図 14 A】



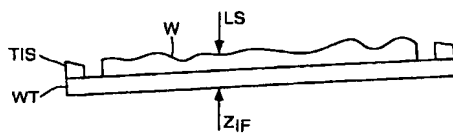
【図 14 D】



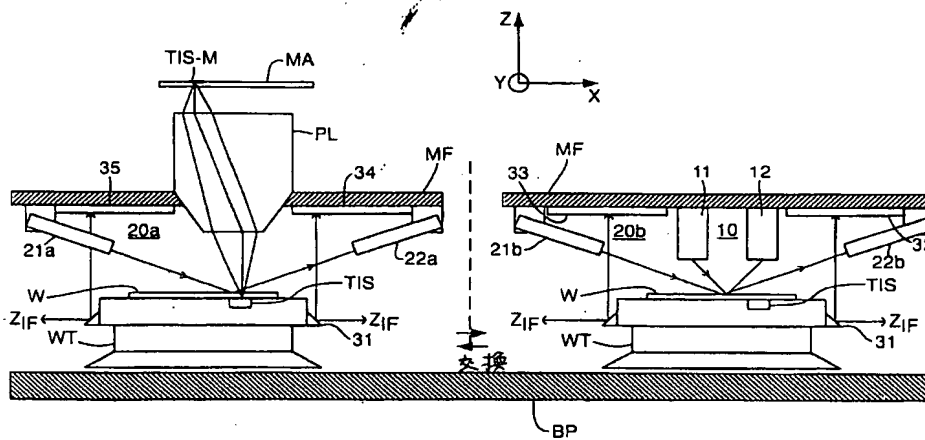
【図1】



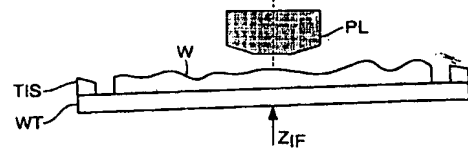
【図4】



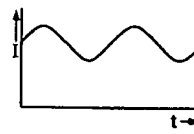
【図8】



【図6】



【図14G】



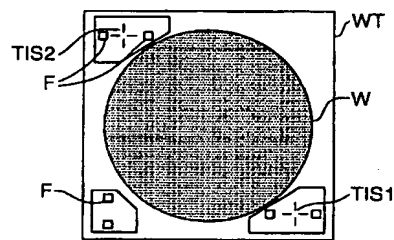
【図14C】



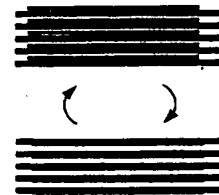
【図14E】



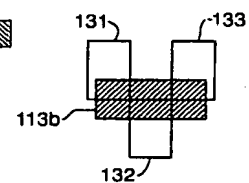
【図7】



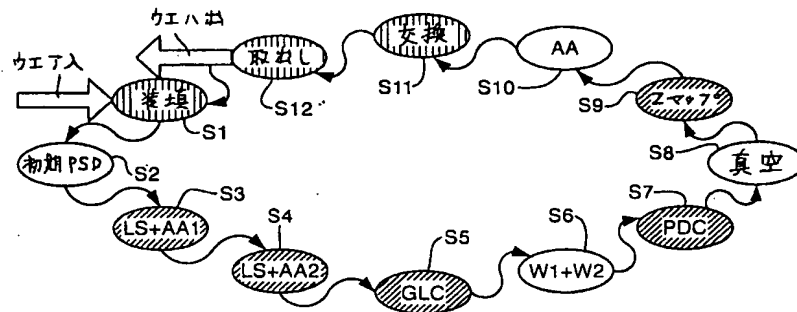
【図14F】



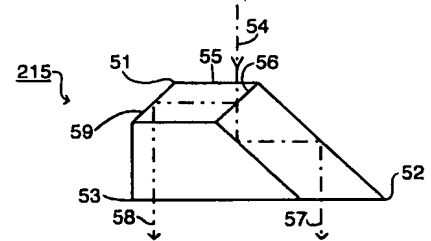
【図15A】



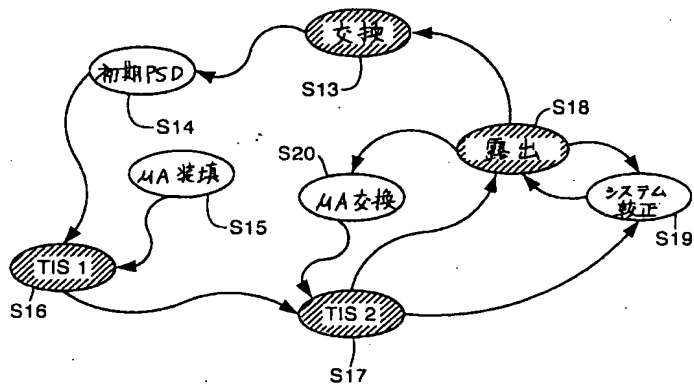
【図 9】



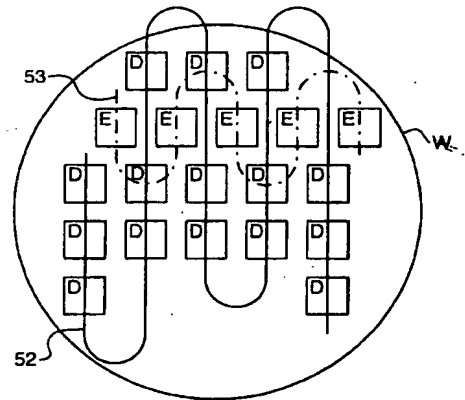
【図 18】



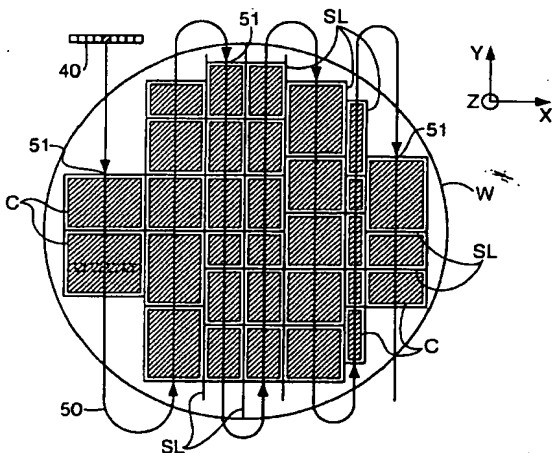
【図 10】



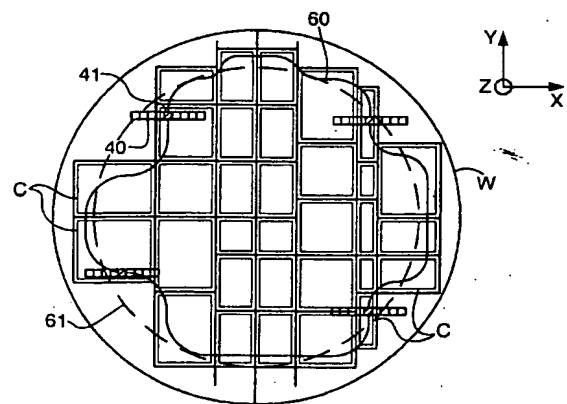
【図 12】



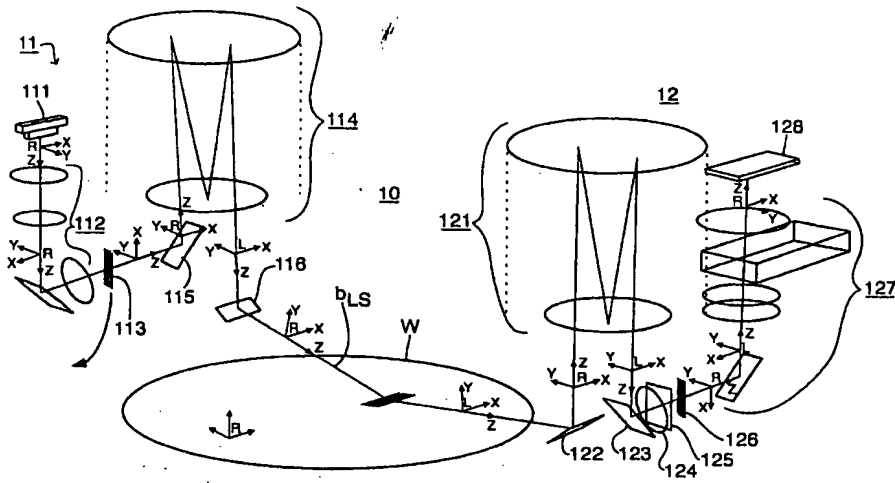
【図 11】



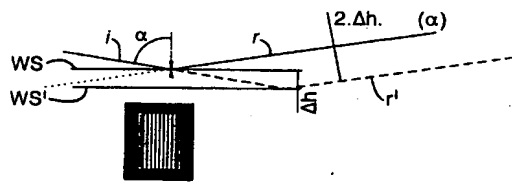
【図 13】



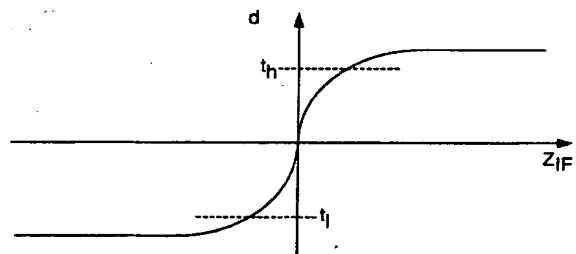
【図14】



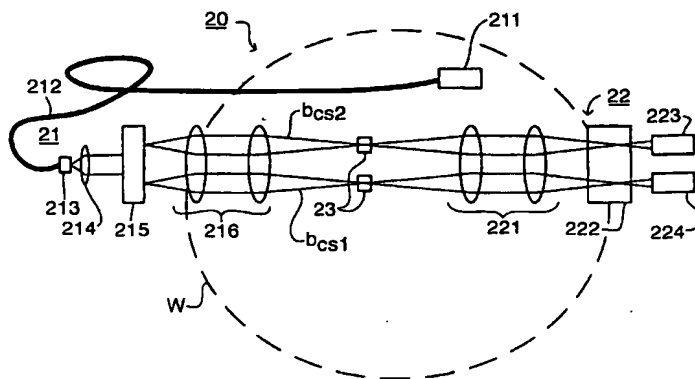
【図14B】



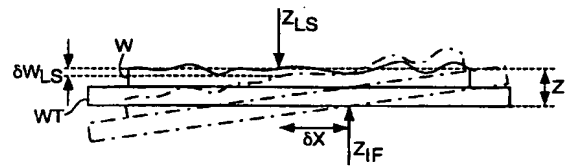
【図15】



【図16】



【図19】



【外國語明細書】

1 Title of Invention

OFF-AXIS LEVELING IN LITHOGRAPHIC
PROJECTION APPARATUS

2 Claims

1. A lithographic projection apparatus comprising:
 - a radiation system for supplying a projection beam of radiation;
 - a first object table provided with a mask holder for holding a mask;
 - a second, movable object table provided with a substrate holder for holding a substrate;
 - a projection system for imaging an irradiated portion of the mask onto a target portion of the substrate; and
 - a positioning system for moving said second object table between an exposure station, at which said projection system can image said mask portion onto said substrate, and a measurement station; characterized in that
 - said second object table has a physical reference surface fixed thereto;
 - and by:
 - height mapping means located at said measurement station and constructed and arranged to measure the height, relative to said physical reference surface, of a plurality of points on the surface of a substrate held on said substrate holder and to create a height map thereof;
 - position measuring means located at said exposure station for measuring the position of said physical reference surface in a first direction substantially perpendicular to said substrate surface, after movement of said second object table to said exposure station; and
 - control means constructed and arranged to control the position of said second object table in at least said first direction, during exposure of said target portion, in accordance with said height map and said position measured by said position measuring means.
2. Apparatus according to claim 1 wherein said control means is further arranged to control the tilt of said second object table about at least one axis perpendicular to said first direction in accordance with said height map.

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3. Apparatus according to claim 1 or 2 wherein said height mapping means comprises a level sensor constructed and arranged to simultaneously measure the position in said first direction of a linear array of points.
4. Apparatus according to claim 1, 2 or 3, wherein said height mapping means comprises a level sensor constructed and arranged to measure the position of a measurement beam reflected by the surface whose position in said first direction is to be measured.
5. Apparatus according to claim 4 wherein said level sensor comprises: a projection grating; projection optics for projecting an image of said projection grating onto the surface whose position in said first direction is to be measured; a detection grating, detection optics for focusing light reflected by said surface to form on said detection grating an image of said projection grating; and a detector for detecting Moiré patterns formed by the overlay of said image of said projection grating on said detection grating.
6. Apparatus according to claim 5 wherein said level sensor further comprises a radiation source constructed and arranged to illuminate said projection grating with polychromatic radiation and wherein said projection optics and said detection optics consist essentially of reflective optical elements.
7. Apparatus according to any one of the preceding claims wherein said height mapping means comprises a level sensor for detecting the position in said first direction of the surface of said substrate at said plurality of points and position detection means for detecting the position in said first direction of said second object table simultaneously with measurements by said level sensor.
8. Apparatus according to claim 7 wherein said position detection means comprise an interferometer.

9. Apparatus according to any one of the preceding claims wherein said position measuring means comprises an image sensor mounted to said second object table and said physical reference surface comprises an upper surface of said image sensor.
10. Apparatus according to any one of the preceding claim, wherein said position measuring means is constructed and arranged to measure the position of said physical reference surface relative to the focal plane of said projection system.
11. Apparatus according to any one of the preceding claims wherein said second object table has a plurality of spaced-apart physical reference surfaces; and said height mapping means is constructed and arranged to measure the height of said plurality of points relative to a reference plane defined by said plurality of physical reference surfaces.
12. Apparatus according to any one of the preceding claims further comprising:
a second height mapping means located at said exposure station constructed and arranged to measure the height, relative to said physical reference surface, of said plurality of points on the surface of a substrate held on said substrate holder and to create a height map thereof; and
calibration means constructed and arranged to compare height maps of a single substrate prepared by each of said first and second height mapping means to derive a relative calibration for separate position detection systems provided at said measurement and exposure stations.
13. A method of manufacturing a device using a lithographic projection apparatus comprising:
a radiation system for supplying a projection beam of radiation;
a first object table provided with a mask holder for holding a mask;
a second, movable object table provided with a substrate holder for holding a substrate; and
a projection system for imaging irradiated portions of the mask onto target

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providing a mask bearing a pattern to said first object table;
providing a substrate having a radiation-sensitive layer to said second object table;
and

imaging said irradiated portions of the mask onto said target portions of the substrate; characterized by the steps of:

before said step of imaging, generating, with the second object table at a measurement station, a height map indicating the height of a plurality of points on the substrate surface relative to a physical reference surface on said second object table;

moving the second object table to said exposure station and measuring the position of said physical reference surface in a first direction substantially perpendicular to said substrate surface; and

during said step of imaging, positioning the second object table in at least said first direction by reference to said height map and said measured position in said first direction of said physical reference surface.

14. A method according to claim 13 wherein, during said step of imaging, said second object table is oriented about at least one axis perpendicular to said first direction by reference to said height map.

15. A method according to claim 13 or 14 wherein said second object table is positioned during said imaging step so as to minimize the squared defocus integrated over the area of said target portion, wherein the defocus comprises the distance in said first direction between the focal surface of said projection lens and the surface of said substrate.

16. A method according to claim 13 or 14 wherein said step of imaging comprises scan imaging a slit image onto said substrate, and said second object table is positioned during said imaging step so as to minimize the squared defocus integrated over the duration of said scanning exposure and the area of said slit image, wherein the defocus comprises the distance in said first direction between the focal surface of said projection lens and the surface of said substrate.

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17. A method according to any one of claims 13 to 16 wherein said step of generating a height map comprises the substeps of:

measuring the position in said first direction of each of said plurality of points on said substrate surface;

simultaneously with each measurement of the position of a point on said substrate surface, measuring the position in said first direction of said second object table; and

subtracting each measured position of said second object table from the corresponding measured position of said substrate surface to generate said height map.

18. A method according to claim 17 wherein said step of generating a height map comprises the initial step of measuring the position in said first direction of said physical reference surface and simultaneously the position in said first direction of said second object table.

19. A method according to any one of claims 13 to 18 comprising the further steps, before said step of generating a height map, of:

measuring the height of a plurality of points on said wafer surface adjacent the perimeter of areas on said substrate that are to be exposed, and determining from the measured heights an overall height and tilt for said substrate and/or local height or tilt values in certain regions of said substrate surface whose height is to be mapped.

20. A method according to any one of claims 13 to 19 further comprising the step, before said step of generating a height map, of calibrating a level sensor to be used in generating said height map by using said level sensor to make a plurality of measurements of the vertical position of at least one predetermined point on said substrate surface with the second object table being positioned at different vertical positions for different ones of said plurality of measurements.

21. A method according to claim 20 wherein said step of calibrating is performed for a plurality of different exposure areas on said substrate and respective resulting

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calibration corrections are applied in generating the height map for exposure areas corresponding in type to those for which the calibration was performed.

22. A device manufactured according to the method of any one of claims 13 to 21.
23. A method of calibrating a lithographic projection apparatus comprising:
a radiation system for supplying a projection beam of radiation;
a first object table provided with a mask holder for holding a mask;
a second, movable object table provided with a substrate holder for holding a substrate; and
a measurement station having a first position detection system for measuring the position of said second object table at said measurement station;
an exposure station having a projection system for imaging irradiated portions of the mask onto target portions of the substrate and a second position detection system for measuring the position of said second object table at said exposure station; the method comprising the steps of:
providing a substrate to said second object table;
at said measurement station, generating a first height map of said substrate by measuring the position in a first direction, substantially perpendicular to the surface of said substrate, of a plurality of points on said substrate surface and simultaneously measuring the position of said second object table using said first position detection system;
at said exposure station, generating a second height map of said substrate by measuring the position in said first direction of said plurality of points on said substrate surface and simultaneously measuring the position of said second object table using said second position detection system; and
comparing said first and second height maps to calibrate said first and second position detection systems.
24. A method of manufacturing devices using a lithographic projection apparatus comprising:

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a first object table provided with a mask holder for holding a mask;
a second, movable object table provided with a substrate holder for holding a substrate; and
a projection system for imaging irradiated portions of the mask onto target portions of the substrate; the method comprising the steps of:
providing a mask bearing a pattern to said first object table;
providing a substrate having a radiation-sensitive layer to said second object table
and
imaging said irradiated portions of the mask onto said target portions of the substrate;
said steps of providing a substrate and imaging being repeated to expose a plurality of substrates; characterized by the steps of:
generating, for each substrate provided to second object table, a height map indicating the height of a plurality of points on the substrate surface; and
comparing the height maps of successively provided substrates to detect correlations in the locations of any unflatnesses that may be indicative of contamination or systematic faults of said second object table.

25. A lithographic projection apparatus comprising:
a radiation system for supplying a projection beam of radiation;
a first, movable object table provided with a mask holder for holding a reflective mask;
a second, object table provided with a substrate holder for holding a substrate;
and
a projection system for imaging an irradiated portion of the mask onto a target portion of the substrate; characterized by
height mapping means constructed and arranged to measure the height, relative to a reference surface, of a plurality of points on the plane of a reflective mask held on said mask holder and to create a height map thereof; and

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control means constructed and arranged to control the position of said first object table in at least said first direction, during exposure of said target portion, in accordance with said height map.

26. A method of manufacturing a device using a lithographic projection apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a first, movable object table provided with a mask holder for holding a reflective mask;

a second object table provided with a substrate holder for holding a substrate;

and

a projection system for imaging irradiated portions of the mask onto target portions of the substrate; the method comprising the steps of:

providing a reflective mask bearing a pattern to said first object table;

providing a substrate having a radiation-sensitive layer to said second object table

and

imaging said irradiated portions of the mask onto said target portions of the substrate; characterized by the steps of:

before said step of imaging, generating, a height map indicating the height of a plurality of points on the mask surface relative to a reference plane on said first object table; and

during said step of imaging, positioning the first object table in at least said first direction by reference to said height map.

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3 Detailed Description of Invention

The present invention relates to height detection and levelling, for example of the substrate and/or mask, in lithographic apparatus. More particularly, the invention relates to a system for off-axis levelling in lithographic projection apparatus comprising:

- a radiation system for supplying a projection beam of radiation;
- a first object table provided with a mask holder for holding a mask;
- a second, movable object table provided with a substrate holder for holding a substrate;
- a projection system for imaging an irradiated portion of the mask onto a target portion of the substrate; and
- a positioning system for moving said second object table between an exposure position, at which said projection system can image said mask portion onto said substrate, and a measurement position.

For the sake of simplicity, the projection system may hereinafter be referred to as the "lens"; however, this term should be broadly interpreted as encompassing various types of projection system, including refractive optics, reflective optics, catadioptric systems, and charged particle optics, for example. The radiation system may also include elements operating according to any of these principles for directing, shaping or controlling the projection beam, and such elements may also be referred to below, collectively or singularly, as a "lens". In addition, the first and second object tables may be referred to as the "mask table" and the "substrate table", respectively. Further, the lithographic apparatus may be of a type having two or more mask tables and/or two or more substrate tables. In such "multiple stage" devices the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposures.

Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the mask (reticle) may contain a circuit pattern corresponding to an individual layer of the IC, and this pattern can be imaged

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onto an exposure area (die) on a substrate (silicon wafer) which has been coated with a layer of photosensitive material (resist). In general, a single wafer will contain a whole network of adjacent dies which are successively irradiated via the reticle, one at a time. In one type of lithographic projection apparatus, each die is irradiated by exposing the entire reticle pattern onto the die in one go; such an apparatus is commonly referred to as a wafer stepper. In an alternative apparatus — which is commonly referred to as a step-and-scan apparatus — each die is irradiated by progressively scanning the reticle pattern under the projection beam in a given reference direction (the "scanning" direction) while synchronously scanning the wafer table parallel or anti-parallel to this direction; since, in general, the projection system will have a magnification factor M (generally < 1), the speed V at which the wafer table is scanned will be a factor M times that at which the reticle table is scanned. More information with regard to lithographic devices as here described can be gleaned from International Patent Application WO 97/33205, for example.

Until very recently, lithographic apparatus contained a single mask table and a single substrate table. However, machines are now becoming available in which there are at least two independently moveable substrate tables; see, for example, the multi-stage apparatus described in International Patent Applications WO98/28665 and WO98/40791. The basic operating principle behind such multi-stage apparatus is that, while a first substrate table is at the exposure position underneath the projection system for exposure of a first substrate located on that table, a second substrate table can run to a loading position, discharge a previously exposed substrate, pick up a new substrate, perform some initial measurements on the new substrate and then stand ready to transfer the new substrate to the exposure position underneath the projection system as soon as exposure of the first substrate is completed; the cycle then repeats. In this manner it is possible to increase substantially the machine throughput, which in turn improves the cost of ownership of the machine. It should be understood that the same principle could be used with just one substrate table which is moved between exposure and measurement position.

The measurements performed on the substrate at the measurement position may, for example, include a determination of the spatial relationship (in X & Y directions) between various contemplated exposure areas on the substrate ("dies"),

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reference markers on the substrate and at least one reference marker (e.g. fiducial) located on the substrate table outside the area of the substrate. Such information can subsequently be employed at the exposure position to perform a fast and accurate X and Y positioning of the exposure areas with respect to the projection beam; for more information see WO 99/32940 (P-0079), for example. This document also describes the preparation at the measurement position of a height map relating the Z position of the substrate surface at various points to a reference plane of the substrate holder. However the reference plane is defined by a Z-interferometer at the measurement position and a different Z-interferometer is used at the exposure position. It is therefore necessary to know accurately the relationship between the origins of the two Z-interferometers.

An object of the present invention is to provide a system for off-axis levelling a substrate in a lithographic projection apparatus that avoids the need to relate the origins of two interferometer systems and enables additional improvements in positioning of the exposure areas during exposure processes.

According to the present invention there is provided a lithographic projection apparatus comprising:

- a radiation system for supplying a projection beam of radiation;
- a first object table provided with a mask holder for holding a mask;
- a second, movable object table provided with a substrate holder for holding a substrate;
- a projection system for imaging an irradiated portion of the mask onto a target portion of the substrate; and
- a positioning system for moving said second object table between an exposure station, at which said projection system can image said mask portion onto said substrate, and a measurement station; characterized in that
 - said second object table has a physical reference surface fixed thereto;
 - and by:
 - height mapping means located at said measurement station and constructed and arranged to measure the height, relative to said physical reference surface, of a plurality of points on the surface of a substrate held on said substrate holder and to create a height map thereof;

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position measuring means located at said exposure station for measuring the position of said physical reference surface in a first direction substantially perpendicular to said substrate surface, after movement of said second object table to said exposure station; and

control means constructed and arranged to control the position of said second object table in at least said first direction, during exposure of said target portion, in accordance with said height map and said position measured by said position measuring means.

According to a further aspect of the present invention there is provided a method of manufacturing a device using a lithographic projection apparatus comprising:
a radiation system for supplying a projection beam of radiation;
a first object table provided with a mask holder for holding a mask;
a second, movable object table provided with a substrate holder for holding a substrate; and

a projection system for imaging irradiated portions of the mask onto target portions of the substrate at an exposure station; the method comprising the steps of:
providing a mask bearing a pattern to said first object table;
providing a substrate having a radiation-sensitive layer to said second object table; and

imaging said irradiated portions of the mask onto said target portions of the substrate; characterized by the steps of:

before said step of imaging, generating, with the second object table at a measurement station, a height map indicating the height of a plurality of points on the substrate surface relative to a physical reference surface on said second object table;

moving the second object table to said exposure station and measuring the position of said physical reference surface in a first direction substantially perpendicular to said substrate surface; and

during said step of imaging, positioning the second object table in at least said first direction by reference to said height map and said measured position in said first direction of said physical reference surface.

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In a manufacturing process using a lithographic projection apparatus according to the invention a pattern in a mask is imaged onto a substrate which is at least partially covered by a layer of energy-sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallisation, oxidation, chemo-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices (dies) will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4.

Although specific reference may be made in this text to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels, thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "exposure area", respectively.

In the present document, the terms "radiation" and "beam" are used to encompass all types of electromagnetic radiation or particle flux, including, but not limited to, ultraviolet radiation (e.g. at a wavelength of 365nm, 248nm, 193nm, 157nm or 126nm), extreme ultraviolet radiation (EUV), X-rays, electrons and ions. Also herein, the invention is described using a reference system of orthogonal X, Y and Z

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directions and rotation about an axis parallel to the I direction is denoted R_i . Further, unless the context otherwise requires, the term "vertical" (Z) used herein is intended to refer to the direction normal to the substrate or mask surface, rather than implying any particular orientation of the apparatus.

Embodiment 1

Figure 1 schematically depicts a lithographic projection apparatus according to the invention. The apparatus comprises:

- a radiation system LA, Ex, IN, CO for supplying a projection beam PB of radiation (e.g. UV or EUV radiation);
- a first object table (mask table) MT provided with a mask holder for holding a mask MA (e.g. a reticle), and connected to first positioning means for accurately positioning the mask with respect to item PL;
- a second object table (substrate or wafer table) WTa provided with a substrate holder for holding a substrate W (e.g. a resist-coated silicon wafer), and connected to second positioning means for accurately positioning the substrate with respect to item PL;
- a third object table (substrate or wafer table) WTb provided with a substrate holder for holding a substrate W (e.g. a resist-coated silicon wafer), and connected to third positioning means for accurately positioning the substrate with respect to item PL;
- a measurement system MS for performing measurement (characterization) processes on a substrate held on a substrate table WTa or WTb at a measurement station;

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- a projection system ("lens") PL (e.g. a refractive or catadioptric system, a mirror group or an array of field deflectors) for imaging an irradiated portion of the mask MA onto an exposure area C (die) of a substrate W held in a substrate table WTa or WTb at an exposure station.

As here depicted, the apparatus is of a transmissive type (i.e. has a transmissive mask). However, in general, it may also be of a reflective type, for example.

The radiation system comprises a source LA (e.g. a Hg lamp, examiner laser, an undulator provided around the path of an electron beam in a storage ring or synchrotron, a laser plasma source or an electron or ion beam source) which produces a beam of radiation. This beam is passed along various optical components comprised in the illumination system, — e.g. beam shaping optics Ex, an integrator IN and a condenser CO — so that the resultant beam PB has a desired shape and intensity distribution in its cross-section.

The beam PB subsequently intercepts the mask MA which is held in a mask holder on a mask table MT. Having passed through the mask MA, the beam PB passes through the lens PL, which focuses the beam PB onto an exposure area C of the substrate W. With the aid of the interferometric displacement and measuring means IF, the substrate tables WTa, WTb can be moved accurately by the second and third positioning means, e.g. so as to position different exposure areas C in the path of the beam PB. Similarly, the first positioning means can be used to accurately position the mask MA with respect to the path of the beam PB, e.g. after mechanical retrieval of the mask MA from a mask library. In general, movement of the object tables MT, WTa, WTb will be realized with the aid of a long stroke module (course positioning) and a short stroke module (fine positioning), which are not explicitly depicted in Figure 1. In the case of a waferstepper (as opposed to a step-and-scan apparatus) the reticle table may be connected only to a short stroke positioning device, to make fine adjustments in mask orientation and position.

The second and third positioning means may be constructed so as to be able to position their respective substrate tables WTa, WTb over a range encompassing both the exposure station under projection system PL and the measurement station under the measurement system MS. Alternatively, the second and third positioning means may be replaced by separate exposure station and measurement station positioning systems for

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positioning a substrate table in the respective exposure stations and a table exchange means for exchanging the substrate tables between the two positioning systems. Suitable positioning systems are described, inter alia, in WO 98/28665 and WO 98/40791 mentioned above. It should be noted that a lithography apparatus may have multiple exposure stations and/or multiple measurement stations and that the numbers of measurement and exposure stations may be different than each other and the total number of stations need not equal the number of substrate tables. Indeed, the principle of separate exposure and measurement stations may be employed even with a single substrate table.

The depicted apparatus can be used in two different modes:

1. In step-and-repeat (step) mode, the mask table MT is kept essentially stationary, and an entire mask image is projected in one go (i.e. a single "flash") onto an exposure area C. The substrate table WT is then shifted in the X and/or Y directions so that a different exposure area C can be irradiated by the beam PB;
2. In step-and-scan (scan) mode, essentially the same scenario applies, except that a given exposure area C is not exposed in a single "flash". Instead, the mask table MT is movable in a given direction (the so-called "scan direction", e.g. the Y direction) with a speed v , so that the projection beam PB is caused to scan over a mask image; concurrently, the substrate table WT_a or WT_b is moved in the same or opposite direction at a speed $V = Mv$, in which M is the magnification of the lens PL (typically, $M \sim 1/4$ or $1/5$). In this manner, a relatively large exposure area C can be exposed, without having to compromise on resolution.

An important factor influencing the imaging quality of a lithographic apparatus is the accuracy with which the mask image is focused on the substrate. In practice, since the scope for adjusting the position of the focal plane of the projection system PL is limited and the depth of focus of that system is small, this means that the exposure area of the wafer (substrate) must be positioned precisely in the focal plane of the projection system PL. To do this, it is of course necessary to know both the position of the focal plane of the projection system PL and the position of the top surface of the wafer. Wafers are polished to a very high degree of flatness but nevertheless deviation of the

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wafer surface from perfect flatness (referred to as "unflatness") of sufficient magnitude noticeably to affect focus accuracy can occur. Unflatness may be caused, for example, by variations in wafer thickness, distortion of the shape of the wafer or contaminants on the wafer holder. The presence of structures due to previous process steps also significantly affects the wafer height (flatness). In the present invention, the cause of unflatness is largely irrelevant; only the height of the top surface of the wafer is considered. Unless the context otherwise requires, references below to "the wafer surface" refer to the top surface of the wafer onto which will be projected the mask image.

According to the invention, after loading a wafer onto the substrate table, the height of the wafer surface Z_{wafer} relative to a physical reference surface of the substrate table is mapped. This process is carried out at the measurement station using a first sensor, referred to as the level sensor, which measures the vertical (Z) position of the physical reference surface and the vertical position of the wafer surface, Z_{LS} , at a plurality of points, and a second sensor, for example a Z-interferometer, which simultaneously measures the vertical position of the substrate table, Z_{T} at the same points. As shown in Figure 2, the wafer surface height is determined as $Z_{\text{wafer}} = Z_{\text{LS}} - Z_{\text{T}}$. The substrate table carrying the wafer is then transferred to the exposure station and the vertical position of the physical reference surface is again determined. The height map is then referred to in positioning the wafer at the correct vertical position during the exposure process. This procedure is described in more detail below with reference to Figures 3 to 6.

As shown in Figure 3, first the substrate table is moved so that a physical reference surface fixed to the substrate table is underneath the level sensor LS. The physical reference surface may be any convenient surface whose position in X, Y and Z on the substrate table will not change during processing of a wafer in the lithographic apparatus and, most importantly, in the transfer of the substrate table between measurement and exposure stations. The physical reference surface may be part of a fiducial containing other alignment markers and should have such properties as allow its vertical position to be measured by the same sensor as measures the vertical position of the wafer surface. In a presently preferred embodiment the physical reference surface is a reflective surface in a fiducial in which is inset a so-called transmission image sensor (TIS). The TIS is described further below.

The level sensor may be, for example, an optical sensor such as that described in US 5,191,200 (P-0039) (referred to therein as a focus error detection system); alternatively, a pneumatic or capacitive sensor (for example) is conceivable. A presently preferred form of sensor making use of Moiré patterns formed between the image of a projection grating reflected by the wafer surface and a fixed detection grating is described below in relation to a second embodiment of the invention. The level sensor may measure the vertical position of a plurality of positions simultaneously and for each may measure the average height of a small area, so averaging out unflatnesses of high spatial frequencies.

Simultaneously with the measurement of the vertical position of a physical reference surface by the level sensor LS, the vertical position of the substrate table is measured using the Z-interferometer, Z_{π} . The Z-interferometer may, for example, be part of a three, five or six-axis interferometric metrology system such as that described in WO 99/28790 (P-0077) or WO 99/32940 (P-0079). The Z-interferometer system preferably measures the vertical position of the substrate table at a point having the same position in the XY plane as the calibrated measurement position of the level sensor LS. This may be done by measuring the vertical position of two opposite sides of the substrate table WT at points in line with the measurement position of the level sensor and interpolating/modelling between them. This ensures that, in the event that the wafer table is tilted out of the XY plane, the Z-interferometer measurement correctly indicates the vertical position of the substrate table under the level sensor.

Preferably, this process is repeated with at least a second physical reference surface spaced apart, e.g. diagonally, from the first physical reference surface. Height measurements from two or more positions can then be used to define a reference plane.

The simultaneous measurement of the vertical position of one or more physical reference surfaces and the vertical position of the substrate table establishes a point or points determining the reference plane relative to which the wafer height is to be mapped. A Z-interferometer of the type mentioned above is effectively a displacement sensor rather than an absolute sensor, and so requires zeroing, but provides a highly linear position measurement over a wide range. On the other hand, suitable level sensors, e.g. those mentioned above, may provide an absolute position measurement with respect to an externally defined reference plane (i.e. nominal zero) but over a

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smaller range. Where such sensors are used, it is convenient to move the substrate table vertically under the level sensor until the physical reference surface(s) is (are) positioned at a nominal zero in the middle of the measurement range of the level sensor and to read out the current interferometer Z value. One or more of these measurements on physical reference surfaces will establish the reference plane for the height mapping. The Z-interferometer is then zeroed with reference to the reference plane. In this way the reference plane is related to the physical surface on the substrate table and the Z_{wafer} height map is made independent of the initial zero position of the Z-interferometer at the measurement station and other local factors such as any unflatness in the base plate over which the substrate table is moved. Additionally, the height map is made independent of any drift in the zero position of the level sensor.

As illustrated in Figure 4, once the reference plane has been established, the substrate table is moved so that the wafer surface is scanned underneath the level sensor to make the height map. The vertical position of the wafer surface and the vertical position of the substrate table are measured at a plurality of points of known XY position and subtracted from each other to give the wafer height at the known XY positions. These wafer height values form the wafer height map which can be recorded in any suitable form. For example, the wafer height values and XY coordinates may be stored together in so-called indivisible pairs. Alternatively, the points at which wafer height values are taken may be predetermined, e.g. by scanning the wafer along a predetermined path at a predetermined speed and making measurements at predetermined intervals, so that a simple list or array of height values (optionally together with a small number of parameters defining the measurement pattern and/or a starting point) may suffice to define the height map.

The motion of the substrate table during the height mapping scan is largely only in the XY plane. However, if the level sensor LS is of a type which only gives a reliable zero reading, the substrate table is also moved vertically to keep the wafer surface at the zero position of the level sensor. The wafer height is then essentially derived from the Z movements of the substrate table, as measured by the Z-interferometer, necessary to maintain a zero readout from the level sensor. However, it is preferable to use a level sensor that has an appreciable measurement range over which its output is linearly related to wafer height, or can be linearized. Such measurement

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range ideally encompasses the maximum expected, or permissible, variation in wafer height. With such a sensor, the need for vertical movement of the substrate table during the scan is reduced or eliminated and the scan can be completed faster, since the scan speed is then limited by the sensor response time rather than by the ability of the short stroke substrate table to track the contour of the wafer in three dimensions. Also, a sensor with an appreciable linear range can allow the heights at a plurality of positions (e.g. an array of spots) to be measured simultaneously.

Next, the wafer table is moved to the exposure station and, as shown in Figure 5, the (physical) reference surface is positioned under the projection lens so as to allow a measurement of its vertical position relative to the focal plane of the projection lens. In a preferred embodiment, this is achieved using one or more transmission image sensors (described below) whose detector is physically connected to the reference surface used in the earlier measurements. The transmission image sensor(s) can determine the vertical focus position of the projected image from the mask under the projection lens. Armed with this measurement, the reference plane can be related to the focal plane of the projection lens and a path for the substrate table in three-dimensions which keeps the wafer surface in optimum focus can be determined. One method by which this can be done is to calculate Z, Rx and Ry setpoints for a series of points along the scan path. The setpoints are determined using a least squares method so as to minimize the difference between the wafer map data and the focus plane of the exposure slit image. For ease of calculation, the relative motion of the exposure slit image and wafer can be expressed as the slit moving relative to a static wafer. The least squares criterion can then be expressed as, for each time t , finding the values $Z(t)$, $Rx(t)$ and $Ry(t)$ which give a minimum value of:

$$LSQ(t) = \frac{1}{s} \cdot \frac{1}{W} \int_{-s/2}^{s/2} \int_{-W/2}^{W/2} [w(x, y) - (Z(t) + x \cdot Ry(t) - y \cdot Rx(t))]^2 dx dy \quad [1]$$

where $w(x, y)$ is the wafer height map and the exposure slit image is a rectangular plane of width s in the scanning direction and length W perpendicular to the scanning direction with its position defined by $z(t)$, $Rx(t)$ and $Ry(t)$. The setpoints and the wafer trajectory can be expressed as functions of either Y (position in the scanning direction)

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or t (time) since these are related by $Y = y_0 + v.t$, where y_0 is the starting position and v is the scanning speed.

As mentioned above, the physical reference surface(s) is (are) preferably a surface in which a transmission image sensor (TIS) is inset. As shown in Figure 7, two sensors TIS1 and TIS2 are mounted on a fiducial plate mounted to the top surface of the substrate table (WT, WTa or WTb), at diagonally opposite positions outside the area covered by the wafer W . The fiducial plate is made of a highly stable material with a very low coefficient of thermal expansion, e.g. Invar, and has a flat reflective upper surface which may carry markers used in alignment processes. TIS1 and TIS2 are sensors used to determine directly the vertical (and horizontal) position of the aerial image of the projection lens. They comprise apertures in the respective surface close behind which is placed a photodetector sensitive to the radiation used for the exposure process. To determine the position of the focal plane, the projection lens projects into space an image of a TIS pattern TIS-M provided on the mask MA and having contrasting light and dark regions. The substrate stage is then scanned horizontally (in one or preferably two directions) and vertically so that the aperture of the TIS passes through the space where the aerial image is expected to be. As the TIS aperture passes through the light and dark portions of the image of the TIS pattern, the output of the photodetector will fluctuate. The vertical level at which the rate of change of amplitude of the photodetector output is highest indicates the level at which the image of TIS pattern has the greatest contrast and hence indicates the plane of optimum focus. An example of a TIS of this type is described in greater detail in US 4,540,277. Instead of the TIS, a Reflection Image Sensor (RIS) such as that described in US 5,144,363 may also be used.

Using the surface of the TIS as the physical reference surface has the advantage that the TIS measurement directly relates the reference plane used for the height map to the focal plane of the projection lens and so the height map can be employed directly to give height corrections for the wafer stage during the exposure process. This is illustrated in Figure 6, which shows the substrate table WT as positioned under the control of the Z-interferometer at a height determined by the height map so that the wafer surface is at the correct position under the projection lens PL.

The TIS surface may additionally carry reference markers whose position is detected using a through-the-lens (TTL) alignment system to align the substrate table to the mask. Such an alignment system is described in EP-0,467,445 A (P-0032), for example. Alignment of individual exposure areas can also be carried out, or may be obviated by an alignment procedure carried out at the measurement stage to align the exposure areas to the reference markers on the wafer stage. Such a procedure is described in EP-0 906 590 A (P-0070) for example.

It will be appreciated that the mask image projected by the projection system PL in a production process, in both step-and-repeat and step-and-scan modes, is not a single point but extends over a significant area in the XY plane. Since the wafer height may vary significantly over this area it is desirable to optimize the focus over the whole of the projection area, rather than just at a single point. In embodiments of the present invention, this can be achieved by controlling not only the vertical position of the substrate table WT, but also its tilt about the X and Y axes (R_x , R_y). With knowledge of the location and extent of the intended exposure areas, the height map generated by the present invention can be used to calculate in advance optimum Z, R_x and R_y position setpoints for the substrate table for each exposure. This avoids the time required for levelling in known apparatus that only measure wafer height when the wafer is positioned under the projection lens and hence increases throughput. The optimum Z, R_x and R_y setpoints may be calculated by various known mathematical techniques, for example using an iterative process to minimize defocus (defined as the distance between the wafer surface and the ideal focal plane), $LSQ(t)$, integrated over the exposure area.

A further advantage is possible in the step-and-scan mode. In this mode, the projection lens projects an image of only part of the mask pattern onto a corresponding part of the exposure area. The mask and substrate are then scanned in synchronism through the object and image focal planes of the projection system PL so that the entire mask pattern is imaged onto the whole exposure area. Although in practice the projection lens is held stationary and the mask and substrate are moved, it is often convenient to consider this process in terms of an image slit moving over the wafer surface. With the height map determined in advance by the present invention, it is possible to calculate a sequence of Z, R_x and R_y setpoints matched to the XY scan path

(usually, scanning takes place in only one direction, e.g. Y). The sequence of setpoints can be optimized according to additional criteria, e.g. to minimize vertical accelerations or tilt motions that might reduce throughput or induce undesirable vibrations. Given a sequence of spaced-apart setpoints, a scanning trajectory for the exposure can be calculated using a polynomial or spline fitting procedure.

Whilst the present invention aims to position the wafer at the optimum position in Z, Rx and Ry for a given exposure, the variations in wafer surface height over the exposure area may be such that the wafer cannot be positioned to give adequate focus over the entire area. Such so-called focus spots can result in an exposure failure. However, with the present invention such failures can be predicted in advance and remedial action can be taken. For example, the wafer may be stripped and recoated without the detrimental effect of further processing a badly exposed wafer. Alternatively, if the predicted failure affects only one or a few devices on the wafer whilst others will be acceptable, throughput may be enhanced by skipping exposures that can be predicted in advance to result in defective devices.

A further advantage of focus-spot detection can be derived from analysis of height maps taken. When large deviations from a global wafer plane are present in a wafer height map, this could indicate focus spots due to substrate unflatness or process influences. Comparing wafer height maps from several wafers can indicate focus spots due to contamination or unflatness of the substrate table. When focus spots appear at identical or near-identical positions for different wafers, this is most likely caused by substrate holder contamination (so-called "chuck-spots"). From one wafer height map, one can also compare the height map (topology) from repeated exposure areas (dies). If large differences occur at certain dies with respect to an average height map, one can suspect focus spots due to either wafer processing or the substrate table. Instead of comparing wafer height maps, the same comparisons can also be done on the derived exposure paths per die, or on the defocus parameters MA, MSD or Moving Focus explained below. When a certain die or wafer deviates much from an average exposure path or defocus parameters, focus spots can also be detected.

All of the above mentioned analysis can be done before a wafer is exposed, and remedial action, such as wafer rejection (processing influences) or substrate holder cleaning (chuck spots), can be taken. With these methods, focus spots can be localised to

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the size of the measurement spot of the level sensor 10. This implies a much higher resolution than previous methods of focus spot detection.

Embodiment 2

A second embodiment of the present invention is shown in Figure 8, which shows only the exposure and measurement stations and only components relevant to the discussion below. The second embodiment utilizes the levelling principle of the present invention described above, together with certain refinements described below.

At the exposure station, to the left of Figure 8, the projection lens PL is shown mounted to metrology frame MF and projecting an image of TIS marker TIS-M on mask MA onto the sensor TIS mounted to wafer table WT. The metrology frame is isolated from the transmission of vibrations from other parts of the apparatus and has mounted on it only passive components used for fine metrology and alignment sensing. The whole metrology frame may be made of a material with a very low coefficient of thermal expansion, such as Invar, so that it provides a very stable platform for the most sensitive measuring devices of the apparatus. The components mounted on the metrology frame MF include mirrors 34 and 35 to which the measurement beams of the Z-interferometer Z_p are directed by 45°-mirrors 31 mounted on the sides of the wafer table WT. To ensure that the Z position of the substrate table can be measured throughout its range of movement in X, the mirrors 34, 35 have a correspondingly large extent in the X direction. To ensure the Z position can be measured throughout the range of Y-movement, the mirrors 31 cover the whole length of the wafer table. Also mounted to the metrology frame MF are the beam generating and receiving parts 21a, 22a of a confidence sensor 20a described further below.

At the measurement station (on the right in Figure 8), the same metrology frame MF carries mirrors 33 and 32 which serve the same function as the mirrors 34, 35 at the exposure station; again mirrors 32, 33 will have a large extent in the X direction to accommodate the required range of movement of the substrate table WT which is just as large as that at the exposure station. Level sensor 10, comprising beam generating part 11 and detection part 12, is also mounted on the metrology frame MF. Additionally, a confidence sensor 20b, essentially the same as confidence sensor 20a at the exposure

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position, is provided. Other measurement devices, for example an alignment module, can also be provided.

As discussed above, the use of the physical reference surface (again in this embodiment this is provided by the upper surface of the TIS) relates the wafer height map to the wafer stage and makes it independent of the zero positions of the two Z-interferometers and certain local factors such as unflatness of the base plate (stone) BP over which the wafer tables move. However, since the wafer height map is generated using the Z-interferometer at the measurement station and the substrate table position is controlled at the exposure station using a different Z-interferometer provided there, any differences as a function of XY position between the two Z-interferometers can affect the accuracy with which the wafer surface is positioned in the focal plane. The principal cause of these variations in an interferometer system of the type used in the present invention is unflatness of the mirrors 32, 33, 34, 35. The 45° mirrors 31 are attached to the wafer table WT and travel with it as it swaps between exposure and measurement stations. Any unflatness of these mirrors therefore has largely the same effect on positioning at the exposure station as at the measurement station, and largely cancels out. However, the mirrors 32, 33, 34 and 35 mounted on the metrology frame MF stay with their respective interferometers and so any differences in the surface contours of the corresponding pairs 32, 34 and 33, 35 can adversely affect the vertical positioning accuracy of the substrate table WT.

The confidence sensors 20a and 20b are used at initial set-up of the apparatus, and periodically as required thereafter, to calibrate the differences between the Z-interferometers at the measurement and exposure stations. The confidence sensors are sensors capable of measuring the vertical position of the upper surface of the wafer at one or more points as the substrate table is scanned underneath it. Confidence sensors 20a and 20b can be similar in design to level sensor 10 but need not be; since they are used only at setup (and for infrequent recalibration) and with a reference wafer rather than production wafers, the design criteria are less onerous and advantage can be taken of this to design a simpler sensor. Conversely, the existence of the projection lens PL at the exposure station will restrict the physical locations available for the confidence sensor at that station, and this also needs to be taken into account in design or selection

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of each confidence sensor. High accuracy is required of the confidence sensors since the calibration they are used for will affect the quality of every exposure.

In the calibration process using the confidence sensor(s), a reference wafer is loaded onto the substrate table. The reference wafer is preferably a bare silicon wafer. There is no requirement for it to be any flatter than a normal bare Si wafer but its surface finish (in terms of reflectivity) is preferably optimized for the confidence sensors. In a preferred embodiment of the invention the reference wafer is preferably polished to maximize its reflectivity and minimize unflatness.

In the calibration procedure, a partial height map of the reference wafer (as usual referenced to the physical reference surface) is generated at the measurement station using the confidence sensor 20b instead of the level sensor 10. This is done in the same manner as with the level sensor 10: the physical reference surface (TIS) is positioned at the zero point of the confidence sensor to zero the Z-interferometer, the wafer is then scanned under the confidence sensor, and the height map is generated from the difference between the confidence sensor and Z-interferometer readings. A height map is also generated at the exposure station using the confidence sensor 20a at the same points as the measurement station height map. For this calibration, the height maps need not be a complete scan of the wafer; they need only cover strips corresponding to the movement of the Z-interferometer beam over the mirrors 32-35. (The order in which the maps are created is not important, provided the wafer is stable on the substrate table whilst both are done.)

Since the height maps represent the same wafer, any differences between them will be caused by differences between the measurement systems used to create them. The two confidence sensors are static, so their effects on the height maps will not be position-dependent and can be eliminated by normalizing the two height maps and/or subtracting static offsets. Any remaining differences will be position-dependent, and the two height maps can be subtracted from one another to generate correction tables (mirror maps) that relates the exposure station Z-interferometer to the measurement station Z-interferometer. These correction tables can be attributed to the differences between the mirrors 33, 35 and 32, 34 attached to the metrology frame MF and can be applied to the wafer height maps generated in a production process, or used to correct one of the Z-interferometers used to generate the map or to position the substrate table

during the exposure. Depending on the precise construction of the Z-interferometers, particularly the metrology frame mirrors and substrate table mirrors, the differences in Z position caused by the unflatnesses of the mirrors in each interferometer system may also be tilt dependent in one or more degrees of freedom (R_x , R_y , R_z). To eliminate this tilt dependence it may be necessary to use the confidence sensors to create several height maps with the wafer stage at various different tilts, from which a number of different correction tables (mirror maps) can be derived, as necessary.

Having described the principle of the off-axis levelling procedure, now will be described some further refinements to it that are employed in the second embodiment, as well as how it is integrated into the production process. Figures 9 and 10 are referred to and respectively show the steps carried out at the measurement station and at the exposure station. In a lithography apparatus using two wafer tables, one table will be going through the steps of Figure 9 whilst a second simultaneously goes through the steps of Figure 10 before they are swapped. In the description below, the "life" of a single wafer is followed from measurement station (Figure 9) to exposure station (Figure 10) and back.

Starting at step S1 in Figure 9, a wafer coated with a photosensitive resist is loaded on to the substrate table WT. (Note that this may generally take place at a loading station separate from the measurement station at which the substrate table is out of range of the interferometer system IF.) The wafer table is moved into the capture range(s) of one or more position sensitive devices (PSDs) so that an initial coarse zeroing of the interferometric metrology system can be performed, step S2. After the initial coarse zeroing, the fine initialization/zeroing of the interferometric system follows in steps S3 and S4. These two steps contain the level sensor measurements (denoted "LS") on the (two or more) physical reference surfaces, which will define the reference plane (fixed to the wafer table) with respect to which the wafer height map is measured. Also, two alignment measurements (denoted "AA") are done on markers located on the same physical reference surfaces, so as to define the horizontal reference positions fixed to the wafer table. These measurements in S3 and S4 effectively zero the interferometric system in all degrees of freedom.

The next step in the levelling procedure is step S5, referred to as the global level contour (GLC). In this step, which is described further below, a wafer capture and an

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initial scan of the wafer with the level sensor is made to determine its overall height and tilt as well as its approximate height at the points where the subsequent detailed scan will move onto or off the wafer. This information enables the substrate table trajectory for the wafer height map scan to be defined.

In step S6, a global alignment of the wafer is done. At least two alignment markers on the wafer are measured (W1 and W2), meaning that their XY position is determined with respect to the reference markers on the TIS fiducials. This determines to what extent the wafer is horizontally rotated (R_z) with respect to the scan direction (y), and is done to be able to correct the wafer rotation such that the wafer height map scans are done parallel to the exposure area axis (i.e. "going straight over the exposure areas").

After that, the levelling procedure continues with measurements necessary for a process dependent correction (PDC). A process dependent correction is necessary with some forms of level sensor, and will now be explained.

The wafer height map must be taken each time a wafer is exposed. If a wafer has already been subjected to one or more process steps, the surface layer will no longer be pure polished silicon and there may also be structures or topology representing the features already created on the wafer. Different surface layers and structures can affect the level sensor readings and in particular can alter its linearity. If the level sensor is optical, these effects may, for example, be due to diffraction effects caused by the surface structure or by wavelength dependence in the surface reflectivity, and cannot always be predicted. To determine the required process dependent correction, an exposure area or die is scanned under the level sensor with the substrate table WT set to several different vertical positions spanning the linear or linearized range of the level sensor 10. The wafer height, i.e. the physical distance between the wafer surface and the reference plane, should not change with the vertical position of the substrate table; it is obtained by subtracting the measurements of the level sensor and Z-interferometer: $Z_{\text{WAFER}} = Z_{\text{LS}} - Z_{\text{IF}}$. Therefore if the determined value of Z_{WAFER} does change with vertical position of the substrate table this indicates that either or both the level sensor or Z-interferometer are not linear or not equally scaled. The Z-interferometer is deemed to be linear since it looks at the mirrors on the wafer table and metrology frame; and in fact is linear to a greater extent than the required accuracy for the wafer height map, at least once the

correction determined by the use of the confidence sensor is applied. Therefore, any differences in the wafer height values are assumed to result from non-linearity or mis-scaling of the level sensor. They, and the knowledge of at which level sensor readings they were observed, can be used to correct the output of the level sensor. It has been found in a presently preferred embodiment of the level sensor that a simple gain correction is sufficient, but a more complex correction may be required for other sensors.

If the wafer to be processed has exposure areas on it that have been subjected to different processes, then a process-dependent correction is determined for each different type of exposure area on the wafer. Conversely, if a batch of wafers having exposure areas that have undergone the same or similar processes are to be exposed, it may only be necessary to measure the process-dependent correction for each type of exposure area once per batch. That correction can then be applied each time that type of exposure area is height-mapped in the batch.

In many IC fabs, the photosensitive resist is applied to the wafer immediately before it is loaded into the lithography apparatus. For this, and other, reasons, the wafer may be at a different temperature than the substrate table when it is loaded and clamped in place. When the wafer cools (or warms) to the same temperature as the substrate table, thermal stresses can be set up because the wafer is clamped very rigidly using vacuum suction. These may result in undesirable distortion of the wafer. Thermal equilibrium is likely to have been reached by the time the steps S2 to S7 have been completed. Therefore, at step S8, the vacuum clamping the wafer to the substrate table is released, to allow the thermal stresses in the wafer to relax, and then reapplied. This relaxation may cause small shifts in the position and/or tilt of the wafer but these are acceptable since steps S2 to S4 are independent of the wafer and S5 and S6 are only coarse measurements. Any shift in the wafer position at this stage does not affect the process-dependent correction since that is a calibration of the level sensor rather than a measurement of the wafer.

After the vacuum has been reapplied, and from here on it is not released again until the exposure process is finished, the Z-map is carried out at step S9. The scan required for the Z-map must measure the height of sufficient points to enable the wafer to be positioned during exposure at the desired accuracy. It is also important that the

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points measured cover the actual area where the wafer is to be exposed; measurements taken over non-exposure areas, such as scribe lanes and so-called mouse bites, may give misleading results. Accordingly, the height mapping scan must be optimized to the specific pattern of exposure areas on the wafer at hand; this is described further below.

Once the Z-map is completed, the advance alignment measurements, step S10, are carried out before the substrate table is swapped, at step S11, to the exposure position. In the advance alignment process, the positions of a number of alignment markers on the wafer relative to the reference markers *F* located on the TIS fiducial (physical reference surface) fixed to the substrate table are accurately determined. This process is not particularly relevant to the present invention and so is not described further herein.

In the swap procedure, the substrate table carrying the height-mapped wafer arrives at the exposure station, step S13 in Figure 10. A coarse position determination of the substrate table is made at step S14 and, if necessary, a new mask MA is loaded onto the mask table MT, step S15. The mask loading process may be carried out, or at least begun, simultaneously with the substrate table swap. Once a mask is in position and a coarse position determination, step S14, has been made, a first TIS scan is carried out using sensor TIS1 at step S16. The TIS scan measures the vertical and horizontal position of the substrate table at which the TIS is located in the aerial image focus of the projection lens, as described above, yielding a focal plane reference. Since the height map generated as step S9 in Figure 9 is referenced to the physical surface in which the TIS is located, the vertical positions of the substrate table necessary to put the wafer surface in the focal plane for the different exposure areas are directly derived. A second TIS scan, step S17, is also carried out using sensor TIS2, yielding a second point for referencing a focal plane.

Once the TIS scans have been completed and the focal plane determined, the exposure process S18 is carried out, optionally after any necessary system calibrations in step S19 (e.g. adjustments to correct for lens heating effects). The exposure process will generally involve the exposure of multiple exposure areas using one or more masks. Where multiple masks are used, after mask exchange S20, one TIS scan S17 can be repeated to update any focal plane changes. Between some or all exposures, the system calibration step S19 may also be repeated. After completion of all exposures, the

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substrate table carrying the exposed wafer is swapped at step S13 for the substrate table carrying the wafer that has meanwhile been undergoing steps S1 to S10 of Figure 9. The substrate table carrying the exposed wafer is moved to the loading station and the exposed wafer taken out so that a fresh wafer can be loaded and the cycle can resume.

To explain the wafer height mapping scan of step S9 of Figure 9, Figure 11 shows an example of a pattern of exposure areas C of various shapes and sizes arranged on a wafer to make best use of the silicon area. The different exposure areas C are separated by scribe lanes SL and generally-triangular unused areas, known as "mouse-bites" are inevitably left between the rectangular exposure areas and the curved edge of the wafer. The scribe lanes are where the wafer will be cut once all production processes have been completed (so as to separate the different devices) and some cutting techniques may require that the scribe lanes in one direction all span the entire width of the wafer; in that case it is convenient to orient these full wafer-width scribe lanes parallel to the scanning direction (e.g. the Y direction) if the apparatus is to be used in step-and-scan mode. The scribe lanes and mouse bites may not be exposed, and so after the wafer has been subjected to a few process steps or depositions of layers they may have very different heights and surface properties than the exposure areas C. Accordingly it is important to disregard any height measurements in these areas, which are not going to be exposed.

A presently preferred embodiment of the level sensor uses a linear array of, e.g., nine optical spots arranged perpendicular to the scanning direction to measure the height at nine points (areas) simultaneously. (Note that the Z-interferometer data can also be interpolated to provide corresponding Z-position data of the substrate table at an array of corresponding level sensor points.) The array of spots is of a size sufficient to cover the width of the widest exposure area that can be exposed in the apparatus.

The presently preferred scanning scheme is to scan the array of spots in a meander path 50 such that the center spot of the array passes along the midline of each column of exposure areas; this midline corresponds to the midline of the illuminated slit in the exposure process. The data thus generated can be directly related to the exposure scan with a minimum of rearrangement or calculation. This method also eliminates part of the mirror unflatness effect, since, at both measurement and exposure stations, scans are carried out with the Z-interferometer beam pointing at the same position on the

mirrors 31 attached to the substrate table. If the column of dies is narrower than the array of spots of the level sensor, data obtained from the spots not lying wholly within the exposure area are ignored. In other embodiments of the level sensor it may be possible to adjust the width of the array of spots to match the width of the exposure areas.

If a wafer has some exposure areas whose center lines are offset in the direction perpendicular to the scanning direction from those of the remainder, a modified scanning scheme may be used to advantage. This situation is illustrated in Figure 12 which shows one row of dies E whose center lines are offset from the remaining dies D. In such a case, the map can be created more quickly and with fewer accelerations for the substrate table by scanning two meander paths. One path, referenced 52 in Figure 12, covers one set of exposure areas D and the other, referenced 53, covers the others E. Of course, other arrangements of the exposure areas may require further modifications to the scanning scheme.

Where the level sensor has a limited linear or linearized range, which is likely the case, the substrate table WT must be scanned underneath it at a vertical position that brings the wafer surface into that range. Once the wafer surface has been found it is a simple matter, by means of a closed feedback loop of the level sensor reading to the substrate table positioning system, to adjust the vertical position of the substrate table WT to keep the wafer surface in the linear or linearized range but it is not so simple to find the wafer surface when the level sensor first moves onto an exposure area from outside the wafer. In a meander path there are several such in-points, referenced 51 and indicated by arrows on the meander path 50 in Figure 11, compounding the problem.

To find the wafer surface at the in-points 51 it is possible to provide a capture spot in advance of the main level sensor spot array. The reflection of the capture spot on the wafer is then directed to a detector that has a wider capture range than is the case for the main spots. This, however, requires additional hardware: a capture spot on both sides of the main spots (before/after) or a restriction to scanning in only one direction. An alternative, not necessarily requiring additional hardware, is to stop the substrate table close to each in-point, perform a wafer capture and measure the wafer surface in the linear or linearized range of the level sensor to approximate the wafer surface

position at the in-point. This however slows down the measurement procedure significantly, which may have undesirable consequences for throughput.

In this embodiment of the invention, these problems are avoided by performing a global level contour scan mentioned above (step S5 in Figure 9) after the wafer surface is captured. The global level contour scan is explained further with reference to Figure 13.

For the global level contour scan the substrate table is first positioned so that a convenient point (preferably near the edge) within an exposure area C is underneath a single capture spot and the main spots of the level sensor (spot array). The wafer surface is found, e.g. by scanning the substrate table vertically until the wafer surface is captured and comes within the linear or linearized range of the main spots, and then the substrate table is scanned so that the central spot 41 traverses a path 60 around the inside of the perimeter of the total exposure area. The capture procedure is described further below. Measurements of the wafer surface height are taken at defined positions around the scan. Where other spots of the array as well as the center spot fall over (exposure areas of) the wafer, the measurements from these spots, as well as the central one, can also be taken. However, measurements should not be taken from spots falling outside the exposure areas. As illustrated, the global level contour path 60 is a winding path following the edges of the exposure areas quite closely; however a smoother path may also be employed and, particularly when the wafer is well filled with exposure areas, a circular course 61 may well suffice and be more convenient. The global level contour may also be arranged as a circle passing over mouse bites, in which case measurements are not taken over the mouse bites, or the data of any measurements taken on mouse bites are disregarded in calculation of the global height and tilt of the wafer.

The data gathered in the global level contour scan are used for two purposes. Firstly data relating to the wafer height in the vicinity of the in-points 51 (see Figure 11) of the height mapping scan to be carried out later are used to predict the wafer height at the in-points 51 so that the substrate table can be brought to the correct height to get the wafer surface position in the linear or linearized level sensor range during the mapping scan. In most cases only a few data points are required for this and they need not be particularly close to the in-points to allow a sufficiently accurate prediction of the wafer height to be determined by interpolation or extrapolation. It is also desirable to know

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the local Ry tilt at the in-points 51 for the height mapping scan, since the level sensor has an array of spots in the X-direction which (preferably) all need to be brought within their linear or linearized ranges. If the global level contour scan is parallel, or nearly parallel, to the Y direction in the vicinity of any in-point, the Ry tilt cannot be accurately determined using data obtained from only a single spot. Where a level sensor having an array of measurement spots spaced apart in the X direction, such as that described below, is used, data from multiple spots can be used to determine a local Ry tilt. Of course, data from spots lying within the exposure area are selected if part of the array falls outside that area.

The second use of the global level contour data is to determine a global, or average, height and tilt (around 2 axes) for the whole wafer. This is done by known mathematical techniques, e.g. a least-squares method, to determine a plane that most closely fits the wafer height data gathered. If the global tilt (sometimes referred to as the "wedge") is greater than a predetermined amount, this may well indicate an incorrect loading procedure. In that case the wafer can be unloaded and reloaded for a retry and even rejected if it continues to fail. The global height and tilt information is used to focus an advance alignment sensor used in step S10 of Figure 9 to accurately determine the spatial relationship of alignment markers on the wafer to reference markers on the substrate stage. The advance alignment sensor and process are described in greater detail in WO 98/39689 (P-0070).

During a wafermap scan, the level sensor 10 provides continuous Z and Ry feedback signals to the substrate table to keep the level sensor 10 in its linear or linearized range. If this feedback loop stops (the level sensor 10 doesn't supply correct numbers) the table is controlled by following a path corresponding to the global wafer wedge (a Z profile according to global Rx).

A presently preferred embodiment of the level sensor 10 is illustrated in Figure 14 and will be explained below additionally with reference to Figures 14A to 14G, which show aspects of the operation of the sensor.

Level sensor 10 comprises a beam generation branch 11 which directs a measurement beam b_{LS} onto the wafer W (or the physical reference plane when the vertical position of that is being measured, or any reflecting surface) and a detection

branch 12 which measures the position of the reflected beam, which is dependent on the vertical position of the wafer surface.

In the beam generation branch, the measurement beam is generated by light source 111, which may be an array of light emitting or laser diodes, or generated elsewhere and passed to "illuminator" 111 by optical fibers. The beam emitted by light source 111 preferably contains a wide band of wavelengths, e.g. from about 600 to 1050 nm, so as to average out any wavelength dependence of interference effects from the wafer surface, particularly after some process steps have been completed. Illumination optics 112, which may include any suitable combination of lenses and mirrors, collect the light emitted by light source 111 and evenly illuminate projection grating 113. Projection grating 113 is shown in greater detail in Figure 14A and consists of an elongate grating 113a, which may be divided to generate an array of separate/discrete spots, with grating lines parallel to its axis, and an additional aperture 113b which forms a capture spot ahead of the main detection spot array on the wafer. The period of the grating will be determined in part by the accuracy at which the wafer surface position is to be measured and may, for example be about $30\mu\text{m}$. The projection grating is positioned with a small rotation around its optical axis such that the grating lines projected on the wafer are not parallel to any wafer coordinate axis, thereby to avoid interference with structures on the wafer which are along the x or y direction. Projection lens 114 is a telecentric system which projects an image of the projection grating 113 onto the wafer W. Projection lens 114 preferably consists essentially or only of reflecting optical elements so as to minimize or avoid chromatic aberration in the projected image; since the projection beam is broadband these cannot easily be eliminated or compensated for in a refractive optical system. Folding mirrors 115, 116 are used to bring the projection beam b_{LS} into and out of the projection lens 114 and permit a convenient arrangement of the components of the beam generation branch.

The projection beam b_{LS} is incident on the wafer at a fairly large angle, α , to the normal, e.g. in the range of from 60° to 80° , and is reflected into the detection branch 12. As shown in Figure 14B, if the wafer surface WS shifts in position by a distance Δh to position WS', then the reflected beam r' will be shifted relative to the beam r , prior to the shift in the wafer surface, by a distance $2\Delta h \cdot \sin(\alpha)$. Figure 14B also

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shows the appearance of the image on the wafer surface; because of the large angle of incidence, the image is spread out perpendicular to the grating lines.

The reflected beam is collected by detection optics 121 and focused on detection grating 126, which is essentially a copy of projection grating 113 and is sub-divided to correspond to the spot-array pattern. Detection optics 121 are directly complementary to projection optics 114 and will also consist essentially or only of reflective elements, to minimize chromatic aberration. Again folding mirrors 122, 123 may be used to enable a convenient arrangement of the components. Between detection optics 121 and the detection grating 126 are positioned a linear polarizer 124 to polarize the light at 45° and a birefringent crystal 125 which causes a shear perpendicular to the grating lines equal in magnitude to the grating period between the horizontal and vertical polarized components of the light. Figure 14C shows the beam as it would be at the detection grating 126 without the birefringent crystal; it is a series of alternating light and dark bands with the light bands polarized at 45° . The birefringent crystal 125 shifts the horizontal and vertical polarization states so that the light bands of the horizontal polarization component fill the dark bands of the vertical polarization component. As shown in Figure 14D, the illumination at the detection grating 126 is therefore uniform grey but has stripes of alternating polarization state. Figure 14E shows the detection grating 126 overlaid on this pattern, which depends on the vertical position of the wafer surface; when the wafer is at a nominal zero vertical position, the detection grating 126 will overly and block half of the light bands of one polarization state, e.g. the vertical, and half of the other state.

The light passed by the detection grating 126 is collected by modulation optics 127 and focused on detector 128. Modulation optics include an polarization modulation device driven by an alternating signal, e.g. with a frequency of about 50kHz, so as to pass the two polarization states alternately. The image seen by the detector 128 therefore alternates between the two states shown in Figure 14F. Detector 128 is divided into a number of regions corresponding to the array of spots whose height is to be measured. The output of a region of detector 128 is shown in Figure 14G. It is an alternating signal with period equal to that of the modulating optics and the amplitude of the oscillations indicates the degree of alignment of the reflected image of the projection grating on the detection grating, and hence the vertical position of the wafer

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surface. As mentioned above, if the wafer surface is at the nominal zero position, the detection grating 126 will block out half of the vertical polarization state and half of the horizontal polarization state so that the measured intensities are equal and the amplitude of the oscillating signals output by the detector regions will be zero. As the vertical position of the wafer surface moves away from the zero position, the detection grating 126 will begin to pass more of the horizontally polarized bands and block more of the vertically polarized bands. The amplitude of the oscillations will then increase. The amplitude of the oscillations, which is a measure of the vertical position of the wafer surface, is not directly linearly related to the vertical position of the wafer surface in nanometers. However, a correction table or formula can readily be determined on initial setup of the apparatus (and periodically recalibrated if necessary) by measuring the constant height of the surface of a bare silicon wafer at various different vertical positions of the substrate table, using the calibrated Z-interferometer and uncalibrated level sensor 10.

To ensure that the measurements of the level sensor and the Z-interferometer are taken simultaneously, a synchronization bus is provided. The synchronization bus carries clock signals of a very stable frequency generated by a master clock of the apparatus. Both the level sensor and Z-interferometer are connected to the synchronization bus and use the clock signals from the bus to determine sampling points of their detectors.

The capture spot 113b passed by the projection grating 113 passes the detection grating, where it is incident on three separate detection regions, two 131, 133 set high and one 132 set low, as shown in Figure 15A. The output from the low detection region is subtracted from those of the high regions. The capture spot detector regions are arranged so that when the wafer surface is at the zero position, the capture spot falls equally on the high and low detection regions and the subtracted output is zero. Away from the zero position, more of the capture spot will fall on one of the detection regions than the other and the subtracted output will increase in magnitude with its sign indicating whether the wafer is too high or too low. The dependence of the subtracted detector output d_{net} on substrate table position Z_{TF} is illustrated in Figure 15. This form of detector output allows a faster zero capture method than a conventional servo feedback. According to the improved method, referred to as "move-until", when the

capture spot detector indicates that the wafer surface is too high or too low, the Z-position actuators of the substrate table are instructed to move the stage in the appropriate direction to bring the wafer surface into the linear or linearized range of the main level sensor array. The movement of the wafer stage continues until the output of the capture spot detector d_{ca} , passes a trigger level τ_h or τ_l according to which direction it is traveling. Crossing the trigger level causes the apparatus control to issue a command to the Z-position actuators to begin a braking procedure. The trigger levels are set so that, in the response time and the time taken to brake the stage motion, the stage will move to, or close to, the zero position. Thereafter the stage can be brought to the zero position under control of the more accurate main level sensor spots. The trigger points will be determined in accordance with the dynamics of the stage and need not be symmetrically spaced about zero detector output. This "move-until" control strategy enables a rapid and robust zero capture without requiring a linear measurement system, and can be used in other situations.

The level sensor described above can be further optimized to improve its performance. Improvement in accuracy in the scan (X) direction can be effected by appropriate signal filtering and this may be adapted to specific process layers observed on partly processed wafers. Additional improvements (for specific process layers) in all directions may be obtained by optimization of the measurement spot geometry, which can be adjusted by changing the illumination optics 112 (to adjust the uniformity and/or angular distribution of the illumination light on the projection grating 113), by changing the projection grating 113 or by adjusting the detection system (size, position and/or angular resolution of the detector and the number of detectors).

A presently preferred form of the confidence sensors 20a, 20b is illustrated in Figures 16 and 17. The beam generation branch 21 comprises a light source 211 (e.g. a solid state laser diode or super-luminescent diode) which emits light of limited bandwidth. It is conveniently situated away from the metrology frame and its output brought to the desired point by an optical fiber 212. The light is output from fiber terminator 213 and directed onto a beam splitter 215 by collimating optics 214. Beam splitter 215 creates two parallel measurement beams b_{ca1} and b_{ca2} which are focused to evenly illuminate respective spots 23 on the wafer W by telecentric projection optics 216. Since the measurement beams of the confidence sensor have a limited bandwidth,

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projection optics 216 can conveniently employ refractive elements. Detection optics 221 collect the reflected beams and focus them at the edge of detection prism 222 which is positioned between detectors 223, 224 and detection optics 221. As shown in Figure 17, which is a side view of detection prism 222 and detector 223, a measurement beam is incident on the back of detection prism 222 and exits through angled faces 222a, 222b. Detector 223 consists of two detector elements 223a, 223b positioned so that light emerging from face 222a of detection prism 222 reaches detector element 223a and that emerging from face 222b reaches detector element 223b. Detector 224 is similar. Outputs of detector elements 223a and 223b are intensity-scaled and subtracted. When the wafer surface is at the zero position, the measurement beam falls symmetrically on faces 222a, 222b of detection prism 222 and equal amounts of light will be directed to detector elements 223a and 223b. These will then give equal outputs and so the subtracted output will be zero. As the wafer surface moves away from the zero position, the position of the reflected beam will move up or down and fall more on one of faces 222a, 222b than on the other resulting in more light being directed to the respective detector element so that the subtracted output will change proportionally. A tilt of the wafer can be determined by comparison of the outputs of detectors 223 and 224.

This arrangement provides a simple and robust height and level detector that can be used as the confidence sensor in the second embodiment of the present invention as well as in other applications. The confidence sensor is primarily intended for initial set up and periodic, e.g. monthly, recalibration of the Z-interferometers of the measurement and exposure stations. However, the confidence sensor described above has a wider capture zone and more rapid response than the TIS used for precise determination of the position of the focal plane of the projection lens PL relative to substrate table WT. Accordingly, the confidence sensor 20a can advantageously be used, when the substrate table is first swapped to the exposure station, to make a coarse determination of the vertical position of the TIS. The height measured by the confidence sensor is related to previously measured best focus position(s) and used to predict a starting point and range for the TIS scan near the expected position of the best focal plane. This means that the TIS scan, described above, can be made shorter and hence quicker, improving throughput.

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A beam splitter 215 that can be used in the confidence sensors is shown in Figure 18. A beam splitter is composed of a number of prisms from the same glass and preferably of equal thickness. The basic operation principle is described using a beam splitter consisting of 3 prisms 51, 52, 53. Prism 51 is trapezoidal in cross-section and the input beam 54 is incident normally on its top face 55 near one side. The position of input beam 54 is such that it meets one side face 56 of first prism 51 which is at 45° to the top face 55. Second prism 52 is joined onto side face 56 of first prism 51 and the join is coated so that a desired proportion of the input beam (half in the present embodiment) continues into second prism 52 to form beam 57 whilst the remainder is reflected horizontally within first prism 51 to form beam 58. Beam 58 reflected in first prism 51 meets the second side face 59 of that prism, which is parallel to the first side face 56 and is reflected downwards out of the lower face of first prism 51 and through top and bottom faces of third prism 53 which are parallel to top face 55 of first prism 51. Second side face 59 may be coated as necessary to ensure total internal reflection of beam 58. Beam 57, which passed into second prism 52, is reflected internally by two parallel faces of second prism 52, which are perpendicular to side face 56 of first prism 51, and emerges from the bottom face of second prism 52 which is parallel to the top face 55 of first prism 51. Beams 57 and 58 are thereby output in parallel, but displaced. The separation between beams 57, 58 is determined by the sizes of prisms 51 and 52. Prism 53 is provided to equalize the optical path lengths of beams 57, 58 so that the imaging optics for both beams can be identical. Prism 53 also supports prism 52 as illustrated but this may not be necessary in some applications. To enhance the reflection of beam 57 at the surface where prisms 52 and 53 meet, a void may be left or a suitable coating provided.

Beam splitter 50 is simple, robust and easy to construct. It provides output beams in parallel (whereas a conventional cubic beam splitter provides perpendicular beams) and with equal path length. The splitting surface can be made polarization selective or not, and in the latter case can divide the input beam intensity evenly or unevenly as desired.

It is a feature of the level and confidence sensors described above, as well as other optical height sensors, that they are insensitive to tilt of the wafer stage about an axis perpendicular to the Z-direction defined by the intersection of the wafer surface WS

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and the focus plane of the measurement spot of the level sensor 10. This is due to the fact that the sensors measure a height over the area of the measurement spot extrapolated to the spot's focus axis. The tilt insensitivity can be used to calibrate the Z-interferometers and the optical sensors towards each other in the XY plane. The procedure for such calibration is described with reference to Figure 19 and the level sensor, but a similar procedure can be used with the confidence sensor or any other similar optical sensor.

The positioning system of the substrate table is linked to the multi-axis interferometer system of which the Z-interferometer is a part, and can be set to apply a rotation about a selected axis in the XY plane using spaced-apart Z-actuators. To align the Z-interferometer measurement position with the level sensor measurement spot, the positioning system is used to rotate the stage about an axis passing through the Z-interferometer measurement position and parallel to, for example, the Y axis. The Z position of the table as measured by the Z-interferometer will remain unchanged during this tilt. If the level sensor and Z-interferometer are exactly aligned, then the wafer surface position will also remain unchanged. However, if the level sensor measurement position is offset from the Z-interferometer position by an amount δX , as shown in Figure 19, then tilting the substrate table WT to the position shown in phantom in that Figure will cause a change δW_{LS} in the level sensor output. The offset δX , and the offset δY in the Y direction, can therefore be quickly determined by detecting any change in level sensor output with tilts about two, preferably perpendicular, axes passing through the Z-interferometer position. The parameters of the interferometer system or the level sensor 10 can then be adjusted to ensure that the Z-interferometer measurement position is exactly opposite the level sensor measurement position.

Where the level sensor uses an array of measurement spots, it cannot always be ensured that the spots are exactly aligned. The above technique can therefore be used to determine any offsets of the individual spots from the nominal position w.r.t the Z-interferometer position. This information can then be used to correct the height map or the level sensor output.

Embodiment 3

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The third embodiment employs the levelling principle of the first embodiment and is the same as that embodiment except as described below. The third embodiment may also make use of the hardware and refinements of the second embodiment, described above. However, the third embodiment makes use of an improved method for optimization of the exposure path. This is explained below with reference to Figure 20.

As discussed above, it is convenient and valid to consider that the substrate stage is stationary and that the exposure slit image moves, even though in practice it is the wafer that moves. The explanation below is given from this view point.

Figure 20 illustrates the notations used below. It should be noted that, although the slit image SI is depicted for clarity in Figure 20 spaced from the wafer surface, the aim of the optimization procedure is to ensure that during an exposure the focus plane of the slit image coincides as far as possible to the wafer surface. Considering a one dimensional wafer whose surface is defined by $w(y)$ and a slit image SI, the moving average (over time) defocus $MA(y)$ corresponding to a coordinate on the wafer can be calculated from:

$$MA(y) = \frac{1}{s} \int_{-s/2}^{s/2} [w(y) - \{z(y+v) - uRx(y+v)\}] dv \quad (2)$$

where the integral is taken over the slit size, s , in the scan direction and the integrand $w(y) - \{z(y+v) - uRx(y+v)\}$ is the focus error on a point of the wafer at a certain moment in time. Similarly, the moving standard deviation for a point on the wafer can be defined as:

$$MSD^2(y) = \frac{1}{s} \int_{-s/2}^{s/2} [w(y) - \{z(y+v) - uRx(y+v)\} - MA(y)]^2 dv \quad (3)$$

which is the defocus variation in time during the actual exposure of that point on the wafer. To minimize the difference between the plane of the exposure slit image and the wafer, a quadratic defocus term is used, defined as follows:

$$MF^2(y) = \frac{1}{s} \int_{-s/2}^{s/2} [w(y) - \{z(y+v) - uRx(y+v)\}]^2 dv \quad (4)$$

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where $MF(y)$ is called the moving focus. It will be seen that $MF(y)$ can also be written in terms of $MA(y)$ and $MSD(y)$ as follows:

$$MF^2(y) = MA^2(y) + MSD^2(y) \quad (5)$$

This means that in the optimization of the exposure path and minimisation of the moving focus over the exposure area, both the moving average and the moving standard deviation are taken into account, in contrast to the simpler least-squares optimization of the first embodiment, which neglects any time, and thus scanning, integration.

Equations [3] and [4] can easily be extended to two dimensions by adding $Ry(t)$ dependency and integrating MF over X from $-W/2$ to $+W/2$, where W is the width of the slit in the X -direction. To calculate the optimization it is convenient to use a frequency domain representation. Calculation in the frequency domain also enables high-frequency variations in the setpoints, that would result in excessive substrate stage accelerations in any or all of the degrees of freedom, to be filtered out, such that the exposure path is optimized for the performance of the substrate table positioning system.

In the above discussion, the optimum focus of the exposure slit image is assumed to conform to a plane; however, this is not necessarily the case: the optimum focus may in fact lie on an arbitrary surface, resulting in a so-called focal plane deviation (FPD). If the contour of that surface over the exposure slit area can be measured using the TIS to create a focus map $f(x,y)$, or calculated, then the resulting data or equations can be added to the equations above so that the wafer motion is optimized for the actual optimum focal surface.

The optimization technique of the third embodiment can result in better focus for scanning systems and smoother substrate stage trajectories, increasing throughput and yield.

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Embodiment 4

In a fourth embodiment, the level sensor is provided with additional features to counteract errors in the measurement of the wafer surface position that may be caused by interference between the beam reflected by the top surface of the resist layer and the beam refracted into the resist layer and reflected by its bottom surface. Otherwise, the fourth embodiment may be the same as any of the first to third embodiments described above.

The interference of beams reflected from said top and bottom surface is largely dependent on the resist properties and wafer surface properties, as well as on the optical wavelength and angle of incidence of the measurement beam. Broadband light sources and detectors are currently used to average out such single-wavelength interference effects. Improvement of this averaging principle can be realized if the wafer surface position is measured in a spectrally resolved manner, whereby a distinct measurement is performed for a number of wavelengths in the broadband measurement beam. To achieve this, it is necessary to make a temporally or spatially separated wavelength (color) system for measuring the wafer surface position. This necessitates changes such as the following to the level sensor's measurement principle.

A first possible change to the level sensor is to replace the continuous broadband light source by one capable of selectively generating light beams of different wavelength ranges (colors). This can, for example, be achieved by selectively interposing different color filters (e.g. on a carousel) at a suitable point in the level sensor's illumination system, by the use of several independently selectable light sources, by using a wavelength-tunable light source, or by using a selected beam portion from a rotating/vibrating prism located in a small broadband beam. The level sensor is then used to take several measurements of the wafer surface at each point, using different wavelengths of light in the measurement beam.

Another option is to replace the broadband detector by one capable of selectively detecting light of different wavelength ranges (colors). This can be achieved, for example, by placement of color filters in the detection optics before the detector, by spatially splitting the measurement beam for different wavelengths using a prism and then detecting the different-wavelength beams on separate detectors, or by any other

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way of spectrally analyzing the broadband-reflected beam to measure the wafer surface position.

Naturally, it is also possible to use a combined approach, whereby both the projection system and the detection system are adapted to achieve spectral resolution.

In the absence of interference effects, each measurement (for each wavelength) should give the same result; consequently, if different results are obtained in such measurements, this indicates the presence of effects as referred to in the first paragraph above. An improved wafer surface position measurement can then be derived using a variety of techniques. For example, discrepant results may be corrected or discarded. Majority voting techniques may also be used. Alternatively, on the basis of a spectral measurement of the wafer surface position, one might even derive real positions by means of a model describing the spectral response of the resist and the wafer surface properties.

Since the described interference effect also depends on the angle of incidence of the measurement beam on the wafer surface, one might also want to vary this angle of incidence so as to evaluate the effect and then correct it. Accordingly, a further possible change to the level sensor is to adapt it such that the wafer surface position can be made using measurement beams at different angles of incidence. One way to achieve this is to define multiple measurement beams having different angles of incidence for the same spot on the wafer, but separate projection and detection optics systems. Alternatively, one can change the optical system so that the same projection and detection systems encompass the different optical axes pertaining to the various measurement beams. Another option, which generates temporally varying angles of incidence, is to use rotating/translating folding mirrors (or other movable components) in the optical systems of the level sensor.

As with the wavelength dependence described above, in the absence of interference effects, measurements at different angles of incidence should give the same result. Therefore, any discrepancies (variation with angle of incidence) can be avoided, compensated for, or modeled in the same way.

The above-mentioned additional features and improvements may, of course, be used together or separately, and in other optical sensors than those described here.

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Embodiment 5

A fifth embodiment of the invention is shown in Figure 21. The fifth embodiment of the invention is a lithography apparatus employing, as the exposure radiation, extreme ultraviolet (EUV) radiation, e.g. of wavelength in the range of 9 to 16nm, and a reflective mask MA'. Functionally at least, the components of the fifth embodiment are generally the same as those of the first embodiment but they are adapted to the exposure radiation wavelength used and their arrangement is adjusted to accommodate the beam path necessitated by the use of a reflective mask. Particular adaptations that may be necessary include optimizing the illumination and projection optics IL', PL' to the wavelength of the exposure radiation; this will generally involve the use of reflective rather than refractive optical elements. An example of an illumination optical system IL' for use with EUV radiation is described in European Patent Application 00300784.6 (P-0129).

An important difference between lithography apparatus using reflective masks and those using transmissive masks, is that with the reflective mask, unflatness of the mask results in position errors on the wafer that are multiplied by the optical path length of the downstream optical system, i.e. the projection lens PL'. This is because height and/or tilt deviations of the mask locally change the effective angle of incidence of the illumination beam on the mask and hence change the XY position of the image features on the wafer.

According to the fifth embodiment of the invention, the effects of unflatness of the mask are avoided or alleviated by making a height map of the mask in advance of the exposure and controlling the mask position in at least one of Z, Rx and Ry during the exposure. The height map can be generated in a similar manner to that described above (i.e. off-axis levelling of the mask at a measurement station); however, it may also be generated with the mask at the exposure station, which may obviate the need to relate the height map to a physical reference surface. The calculation of the optimum position(s) of the mask during the exposure or exposure scan (the exposure path) can be equivalent to that described above, but it may also be a coupled optimization of wafer and mask exposure paths. However, for a mask, it may be advantageous to place greater weight in the optimization calculations on tilt deviations, since these will have a greater effect on the position at the wafer.

It should be explicitly noted that a lithographic projection apparatus according to the current invention may contain two (or more) substrate tables and/or two (or more) mask tables. In such a scenario, it is possible for a first substrate on a first substrate table to be undergoing height-mapping at the measurement station while a second substrate on a second substrate table is concurrently undergoing exposure at the exposure station; and similarly in the case of multiple mask tables. Such a construction can greatly increase throughput.

It should also be explicitly noted that the current invention can be applied to substrate leveling alone, to mask leveling alone, or to a combination of substrate leveling and mask leveling.

Whilst we have described above specific embodiments of the invention it will be appreciated that the invention may be practiced otherwise than as described. The description is not intended to limit the invention.

4 Brief Description of Drawings

The present invention will be described below with reference to exemplary embodiments and the accompanying schematic drawings, in which:

Figure 1 depicts a lithographic projection apparatus according to a first embodiment of the invention;

Figure 2 is a view showing how the wafer height is determined from measurements by the level sensor and the Z-interferometer;

Figures 3 to 6 are views showing various steps of the off-axis levelling procedure according to the present invention;

Figure 7 is a plan view of a substrate table showing the sensors and fiducials used in the off-axis levelling procedure according to the present invention;

Figure 8 is a side view of the exposure and measurement stations in a second embodiment of the invention;

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Figure 9 is a flow diagram illustrating various steps of the measurement process carried out at the measurement station of the second embodiment of the invention;

Figure 10 is a flow diagram illustrating various steps of the exposure process carried out at the exposure station of the second embodiment of the present invention;

Figure 11 is a diagram illustrating the scan pattern usable to measure the height map of the present invention;

Figure 12 is a diagram illustrating an alternative scan pattern usable to measure the height map of the present invention;

Figure 13 is a diagram illustrating the global level contour process in the second embodiment of the present invention;

Figure 14 and its sub-Figures A to G illustrate the structure and operation of a presently preferred embodiment of a level sensor usable in the invention;

Figure 15 is a graph showing detector output vs. substrate table position for a capture spot of the level sensor of Figure 14;

Figure 15A is a diagram showing the arrangements of detector segments for the capture spot of the level sensor of Figure 14;

Figures 16 and 17 are diagrams illustrating a presently preferred embodiment of a confidence sensor usable in the second embodiment of the invention;

Figure 18 is a diagram of a beam splitter usable in the confidence sensor of Figures 16 and 17;

Figure 19 is a diagram used to explain a Z-interferometer calibration procedure usable in embodiments of the invention;

Figure 20 is a diagram illustrating the notation used in describing an exposure trajectory optimization procedure according to a third embodiment of the invention; and

Figure 21 depicts a lithographic projection apparatus according to a fifth embodiment of the invention.

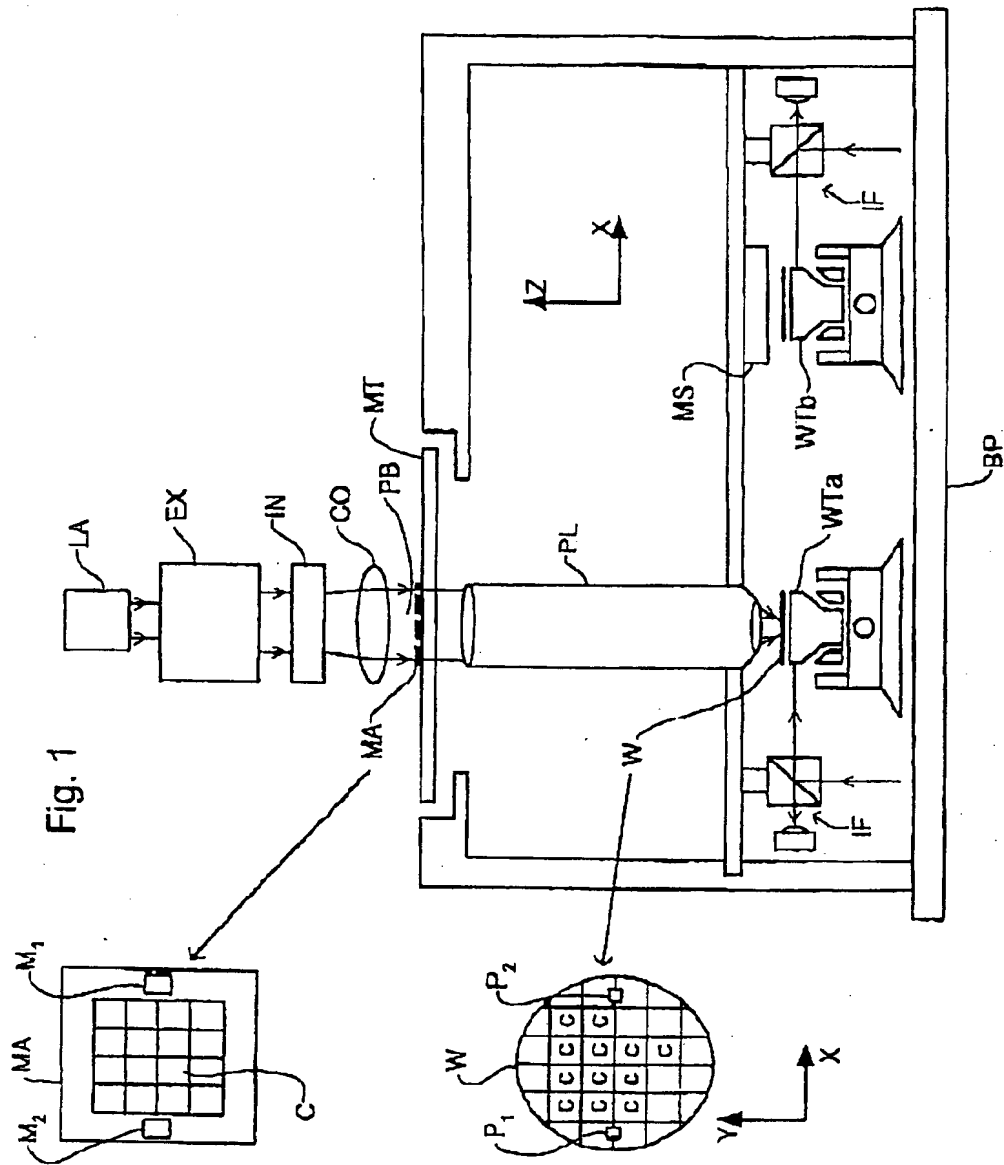


Fig. 2

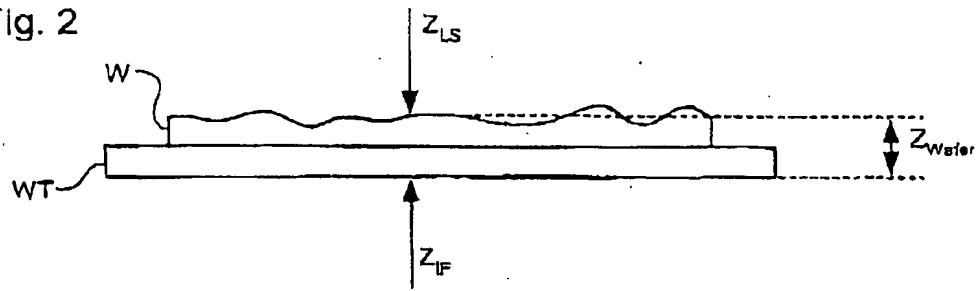


Fig. 3

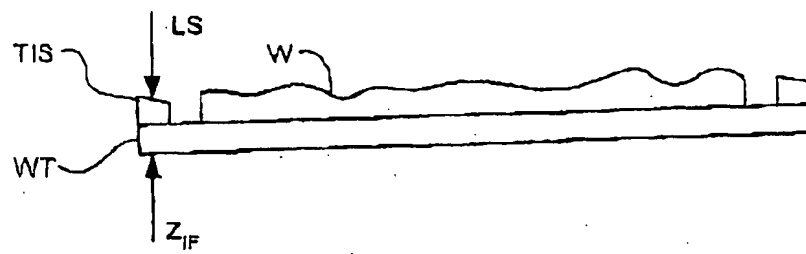


Fig. 4

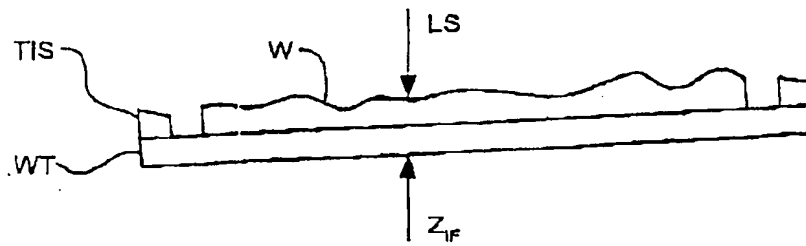


Fig. 5

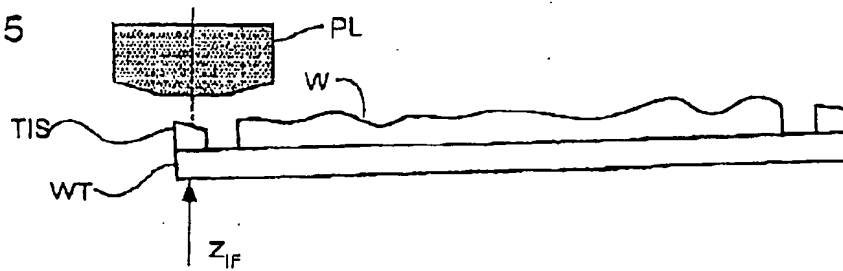
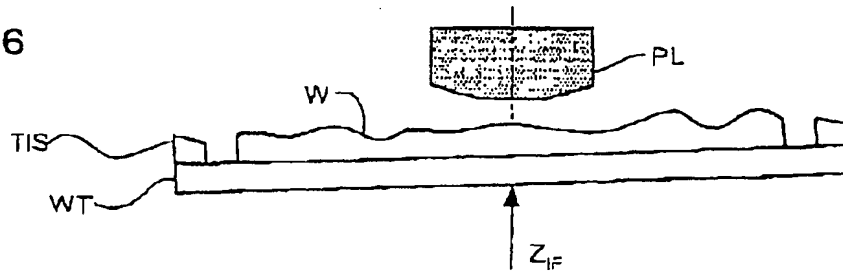


Fig. 6



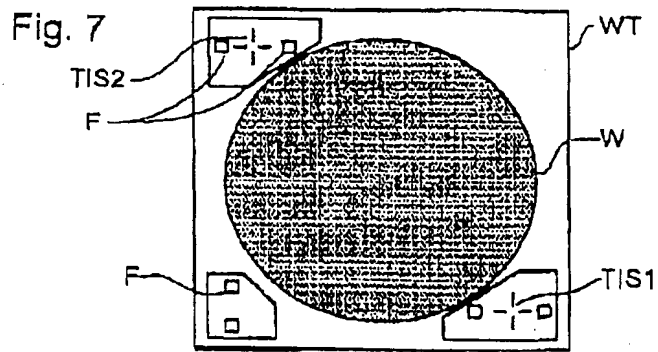


Fig. 9

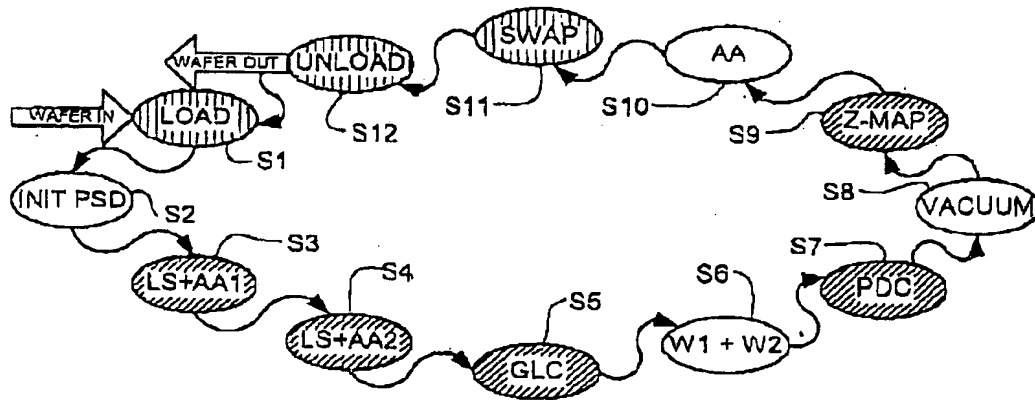
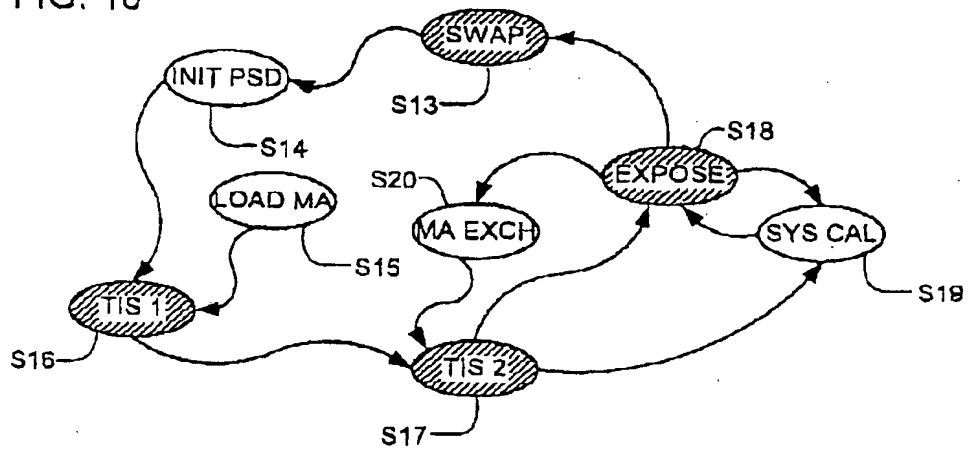


FIG. 10



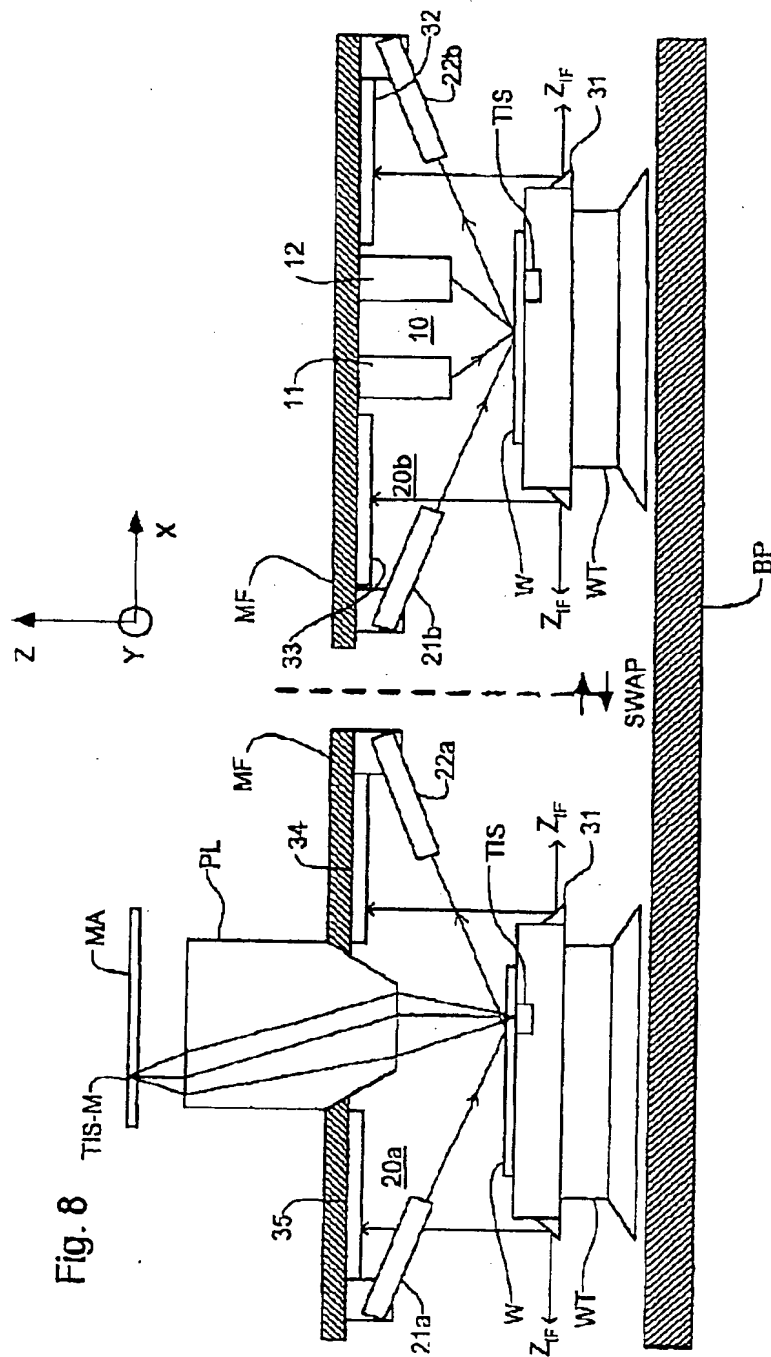


Fig. 11

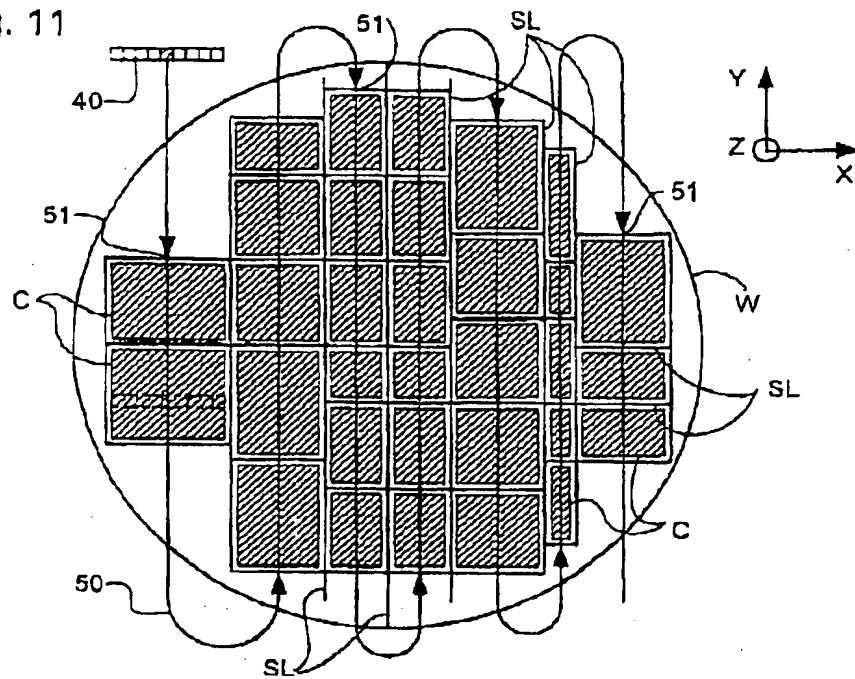


Fig. 12

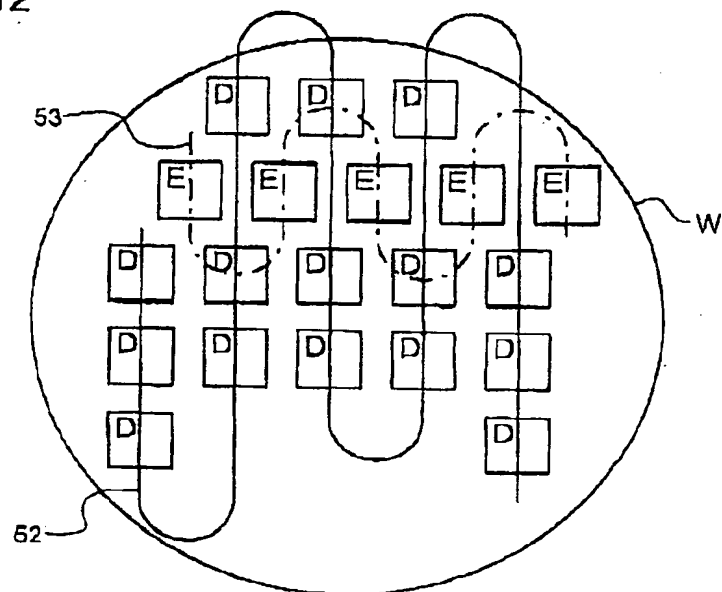


Fig. 13

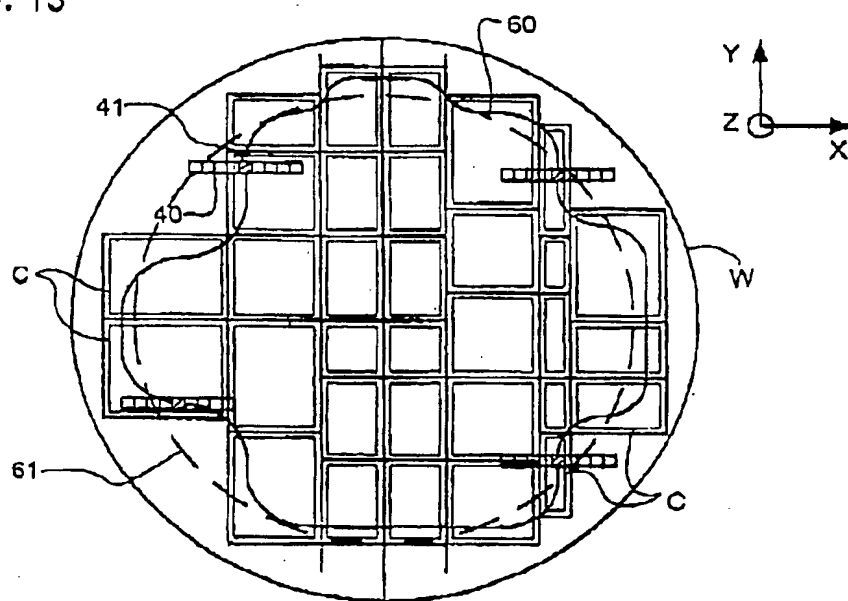


Fig. 15

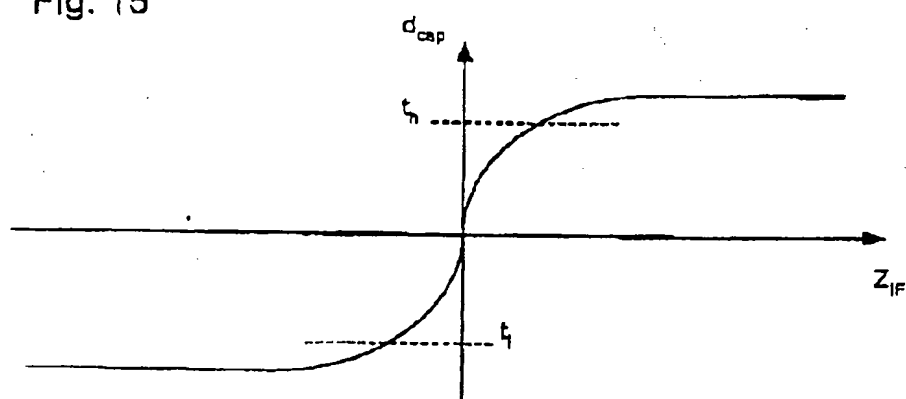
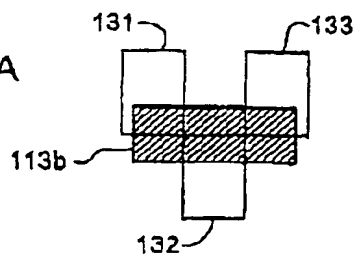


Fig. 15A



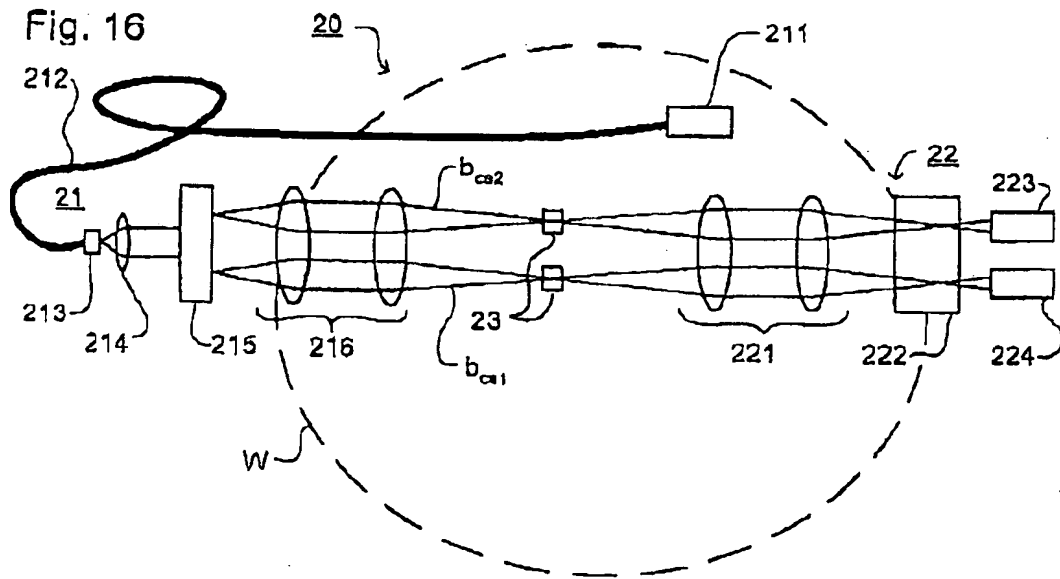


Fig. 17

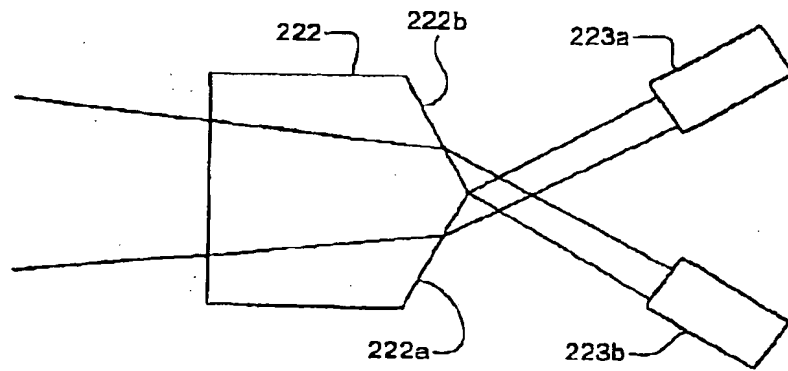


Fig. 18

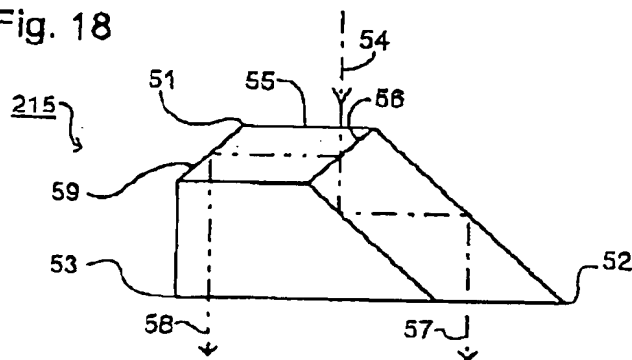


Fig. 19

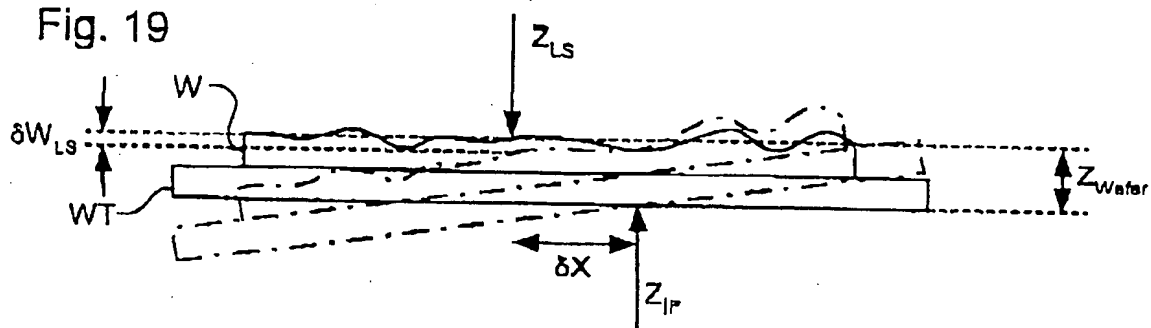


Fig. 20

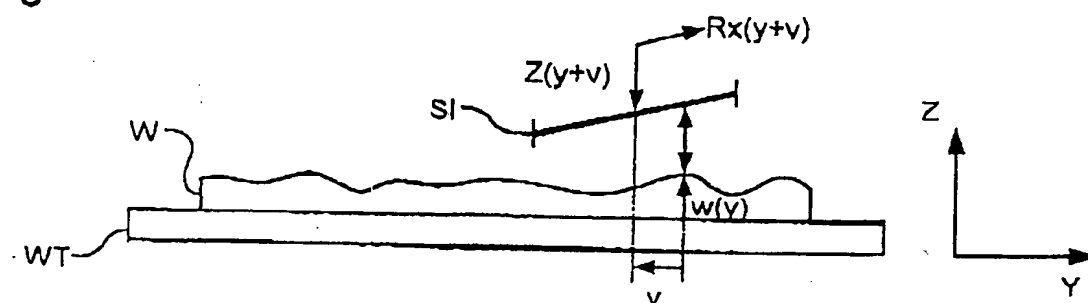
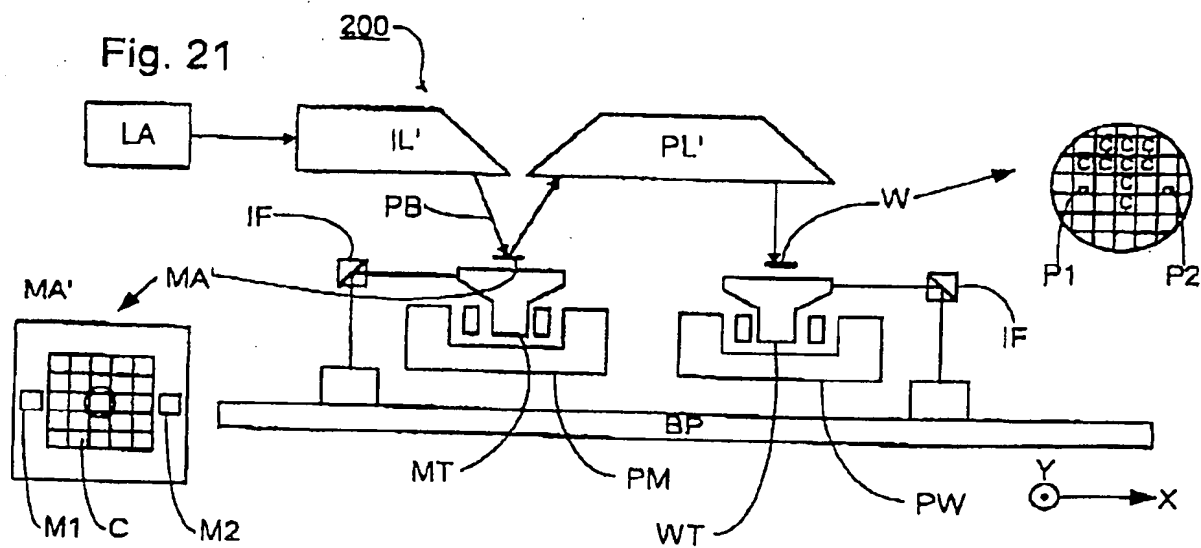


Fig. 21



1 Abstract

In an off-axis levelling procedure a height map of the substrate is generated at a measurement station. The height map is referenced to a physical reference surface of the substrate table. The physical reference surface may be a surface in which is inset a transmission image sensor. At the exposure station the height of the physical reference surface is measured and related to the focal plane of the projection lens. The height map can then be used to determine the optimum height and/or tilt of substrate table to position the exposure area on the substrate in best focus during exposure. The same principles can be applied to (reflective) masks.

2 Representative Drawing

Fig. 8